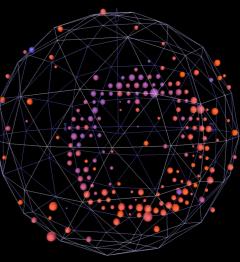


MiniBooNE Oscillation Update

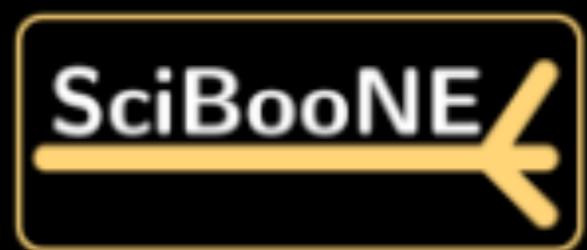
Morgan Wascko
Imperial College London



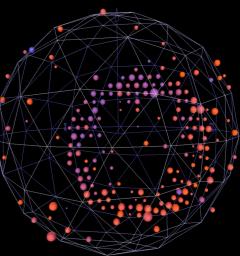
Outline



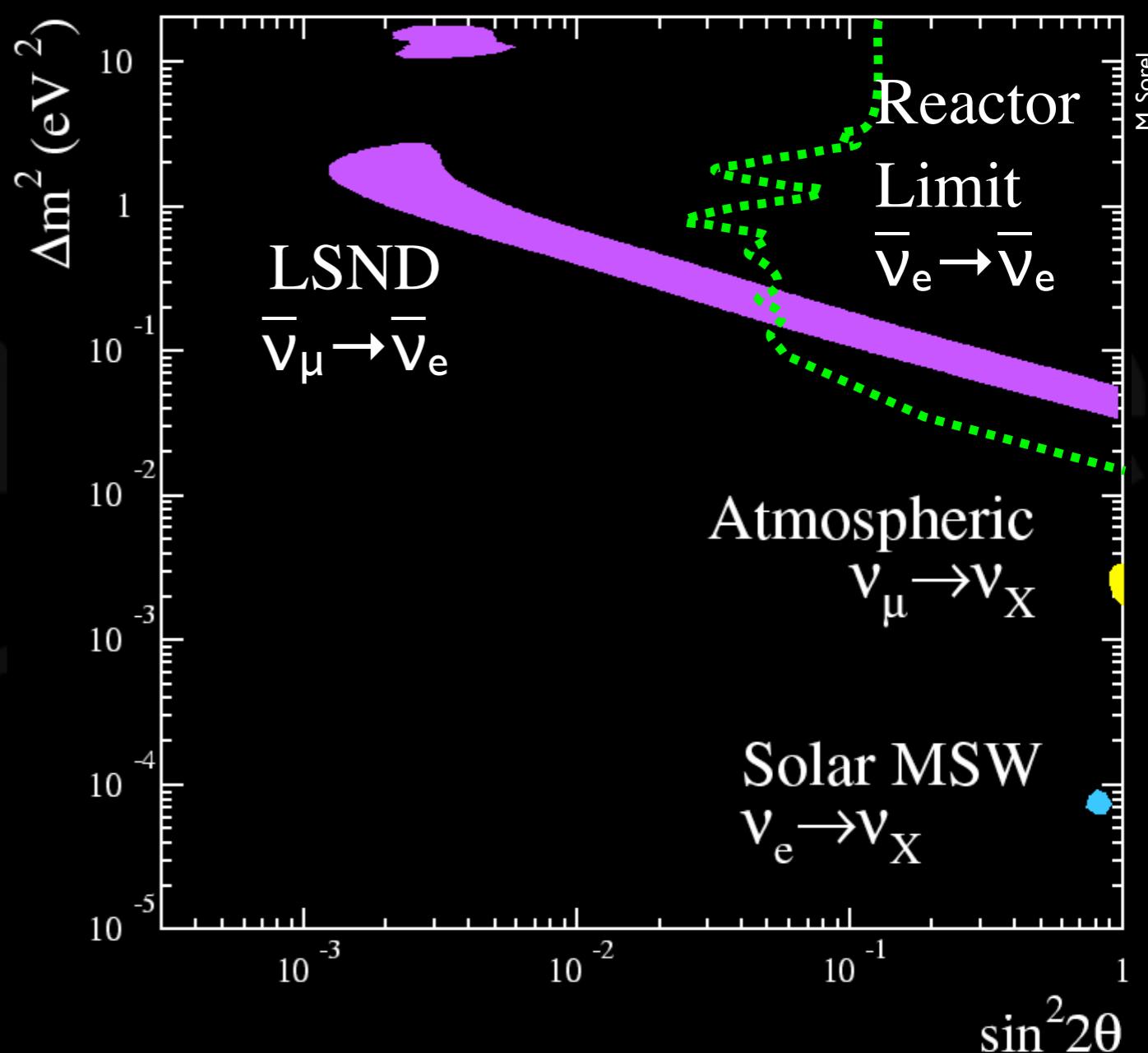
- Introduction
 - MiniBooNE first result
 - MiniBooNE $\nu_\mu \rightarrow \nu_e$ oscillation updates
 - Oscillation outlook



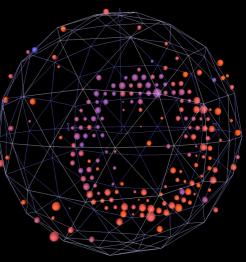
The Problem



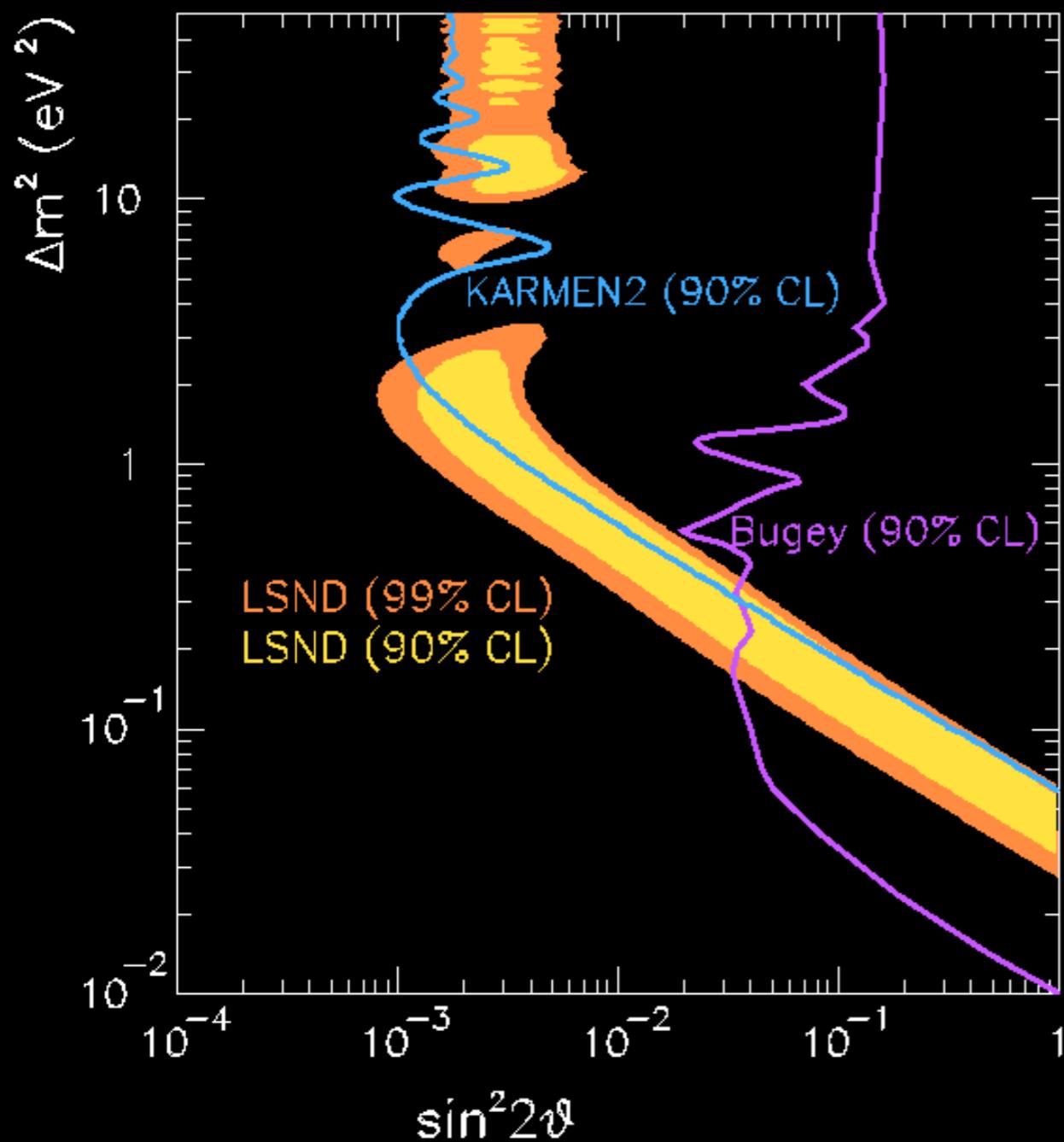
- Three different neutrino oscillation signals
- Three independent Δm^2
- Problem:
We only need two!
- Explanation requires physics well beyond the standard model
- Is it true?



Verifying LSND

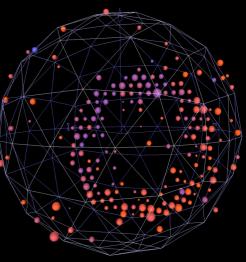


$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{12} \sin^2(1.27 \Delta m_{12}^2 \frac{L}{E})$$

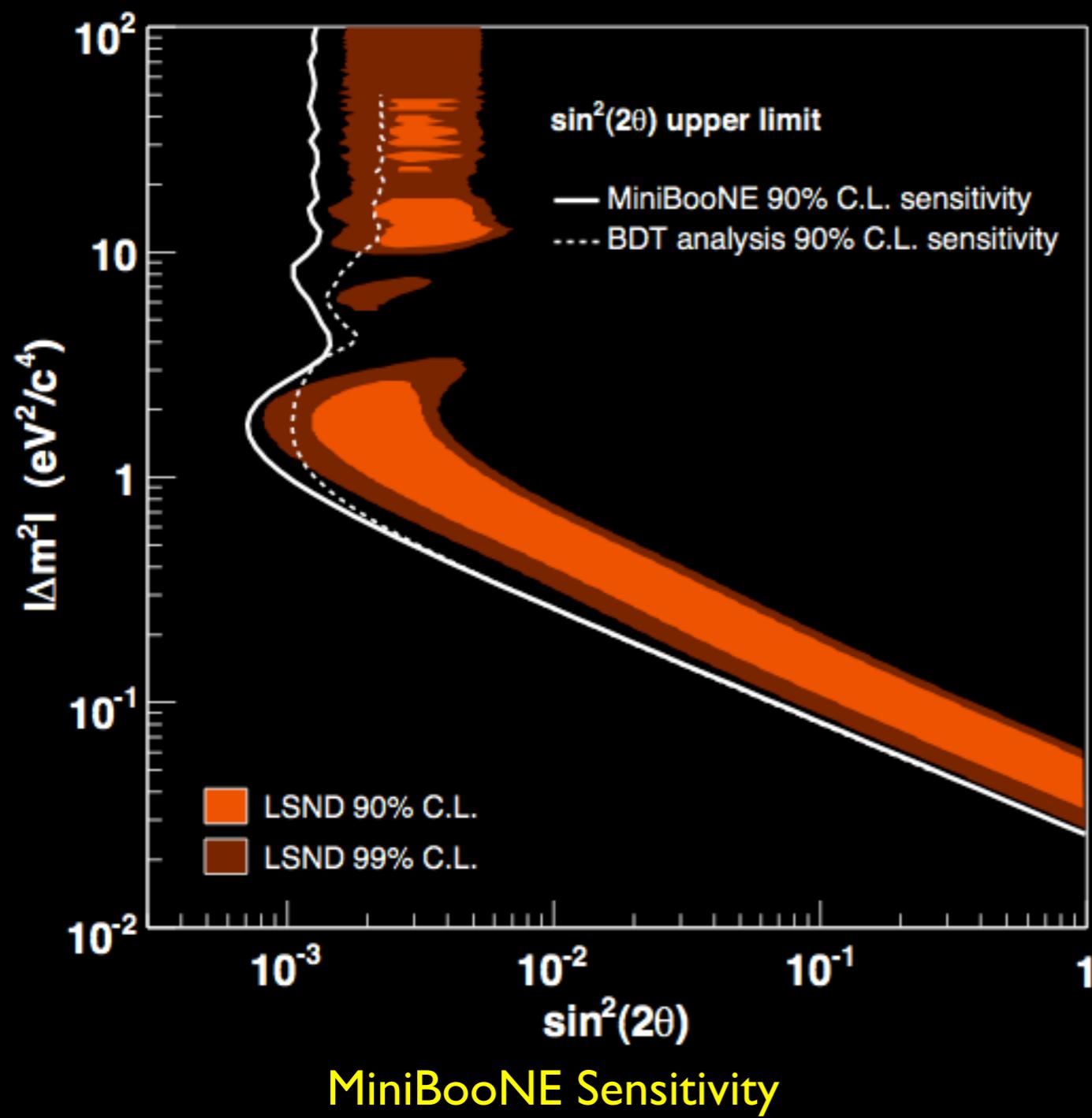


- LSND interpreted as 2 ν oscillation
- Verification requires same (L/E) and high statistics
- Different systematics
- MiniBooNE chose higher L and E
- Strategy: search for ν_e excess in ν_μ beam

Verifying LSND

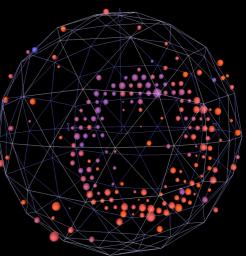


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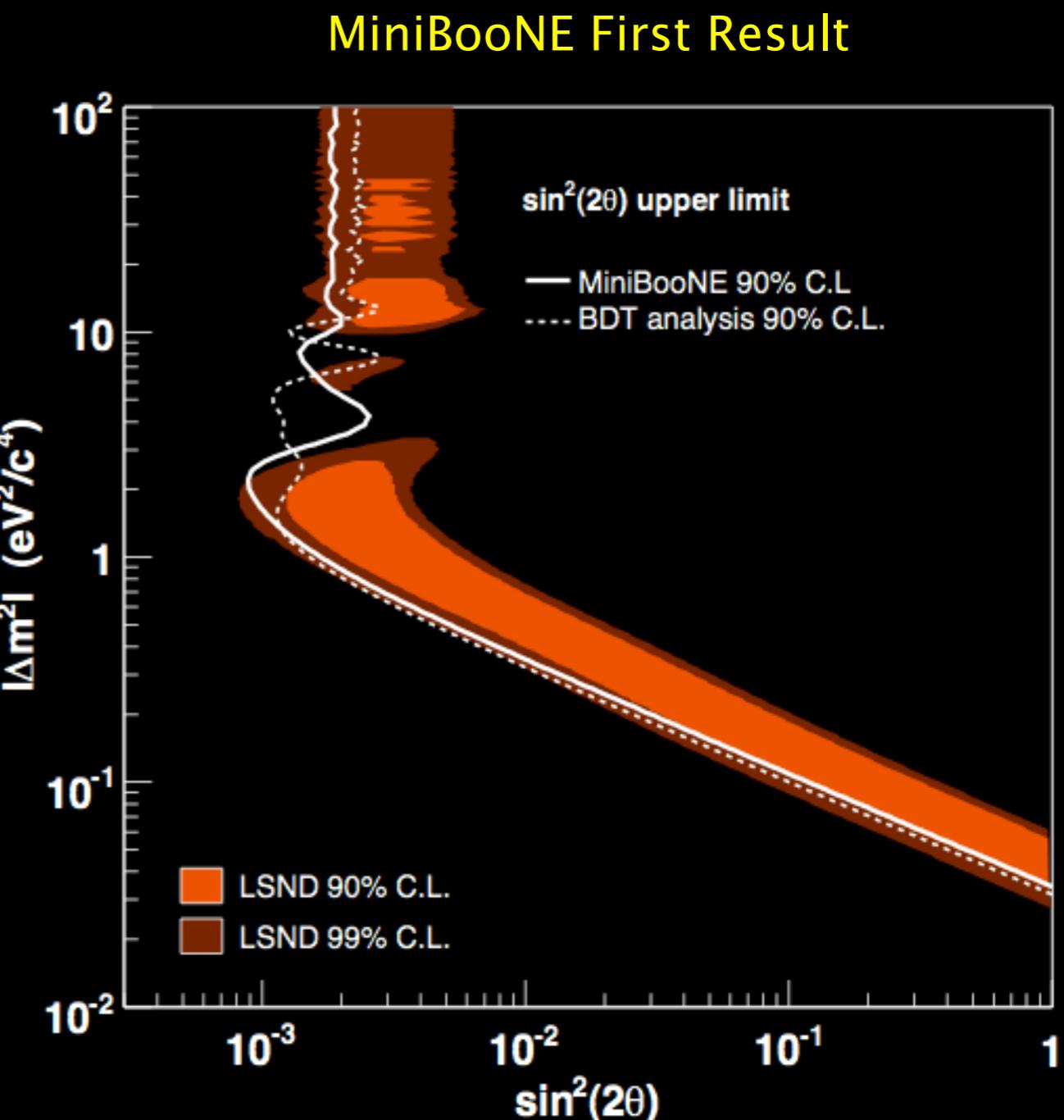


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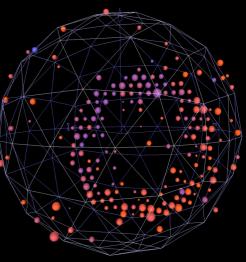
First Exclusion Curve



- No evidence for $\nu_\mu \rightarrow \nu_e$ 2 ν appearance only oscillation
- Independent second analysis finds similar result
- Incompatible with LSND at 98% CL
- cf. KARMEN2 compatible at 64%



Phys.Rev.Lett. 98 231801 (2007)



What Does It Mean?

- With the blind analysis, we have asked the question:

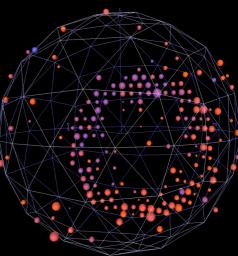
Do $\nu_{\mu}S$ oscillate directly to ν_eS with
 $\Delta m^2 \sim 1 \text{ eV}^2$, ala LSND?

- We have a clear answer:

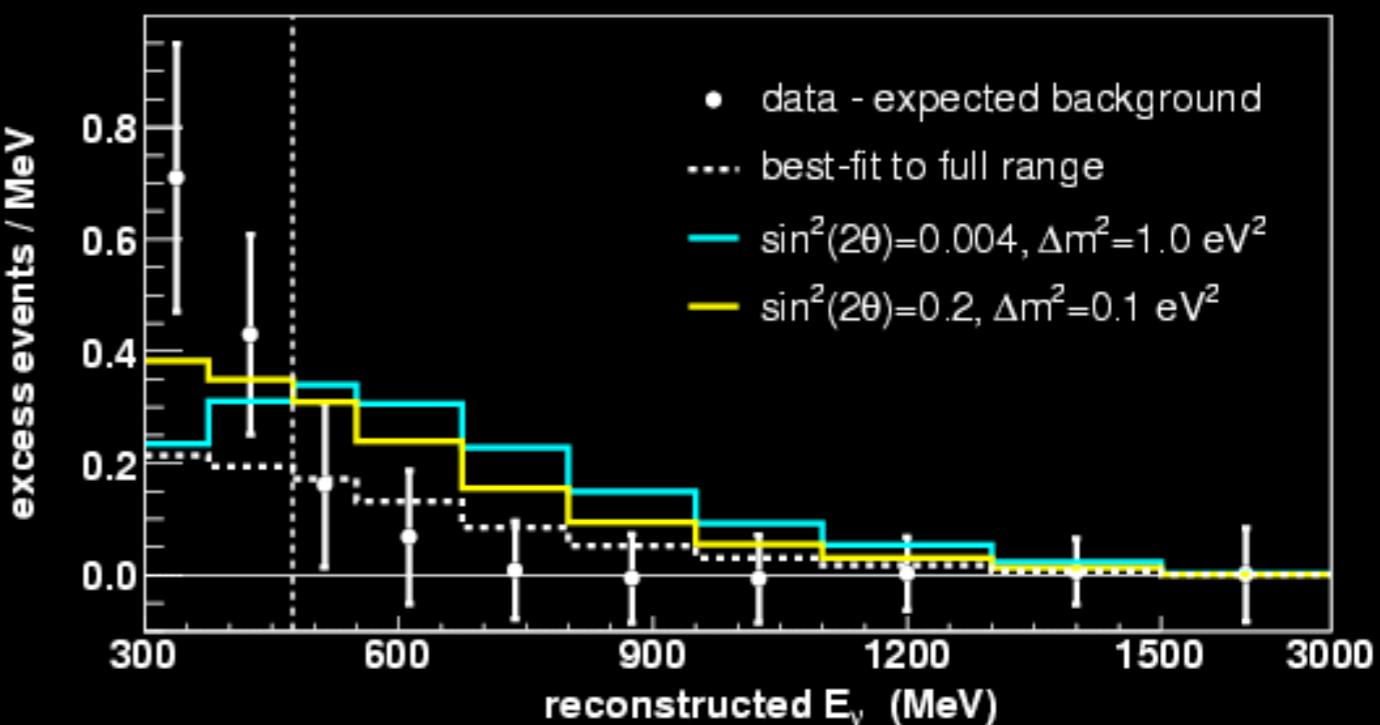
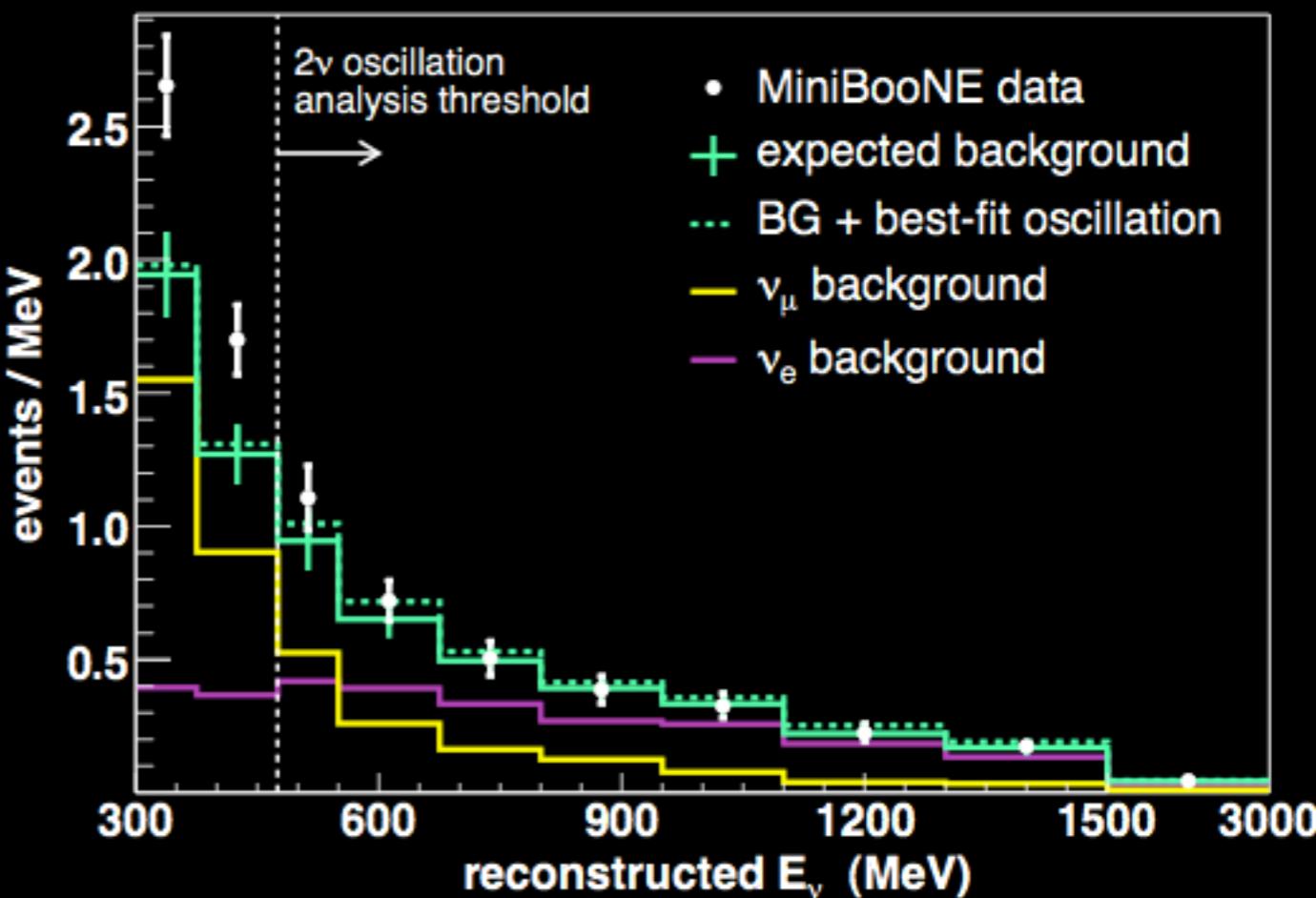
NO

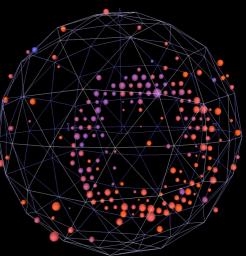
More work yet to do...

At lower energy...



- Lowering the energy threshold reveals ν_e excess
- Excess not consistent with LSND signal
- But what is it??
- Lots of new work to report...



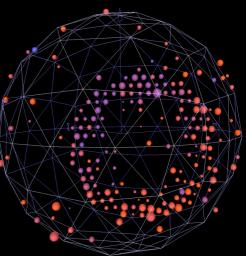


Low Energy Updates

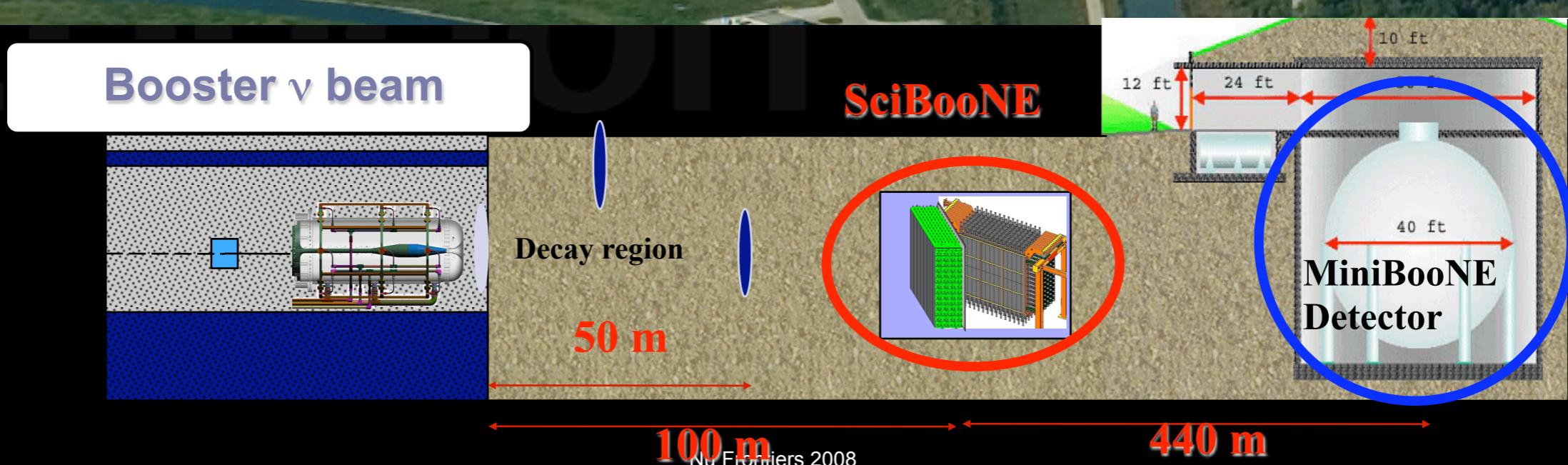
(Experimental Overview)

- Looking at new/more data
- NC π^0 and delta decays
- Hadronic processes and uncertainties
- “Dirt” BGs

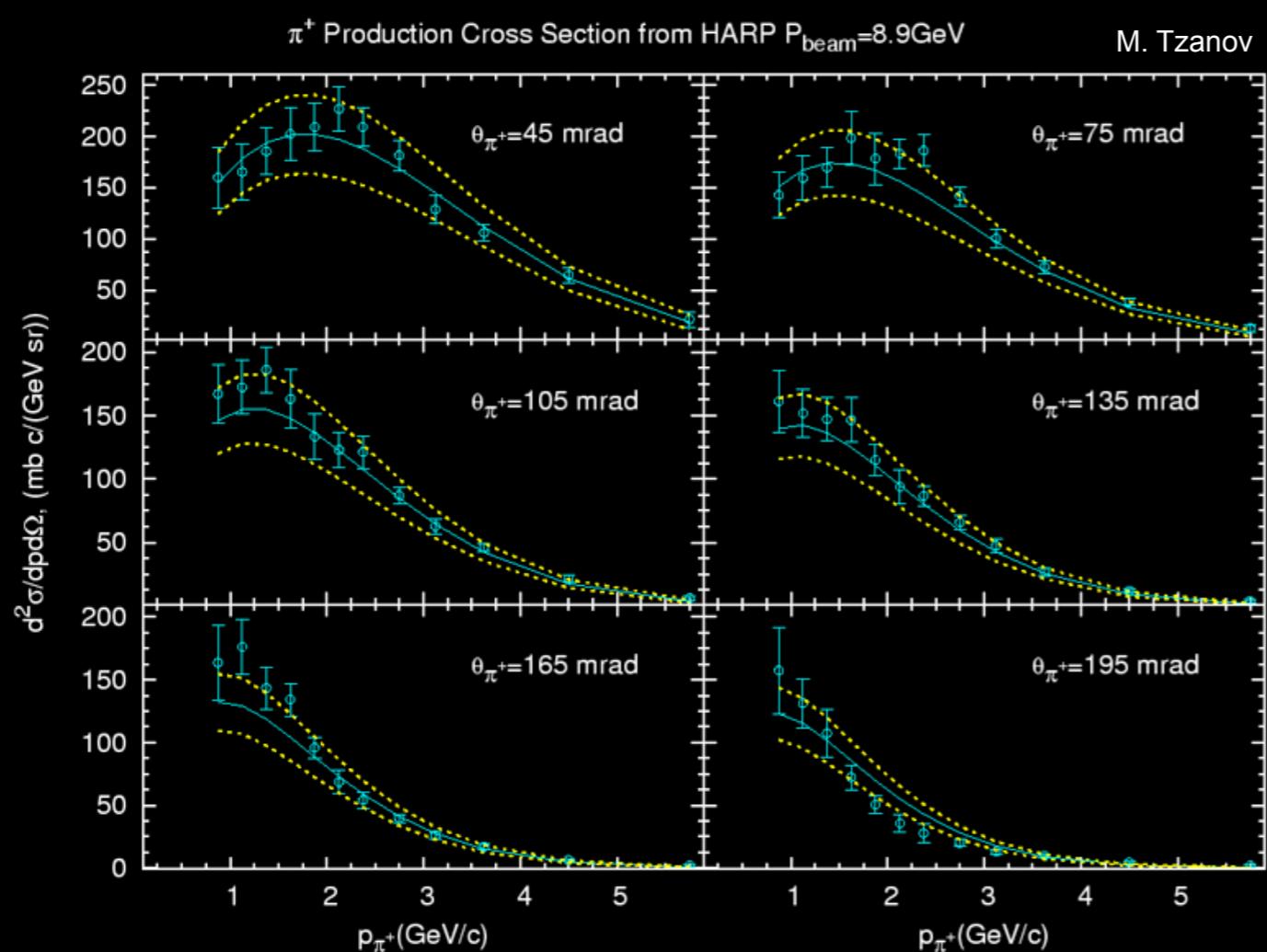
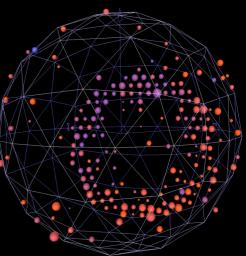
Experimental Overview



Fermilab Visual Media Services

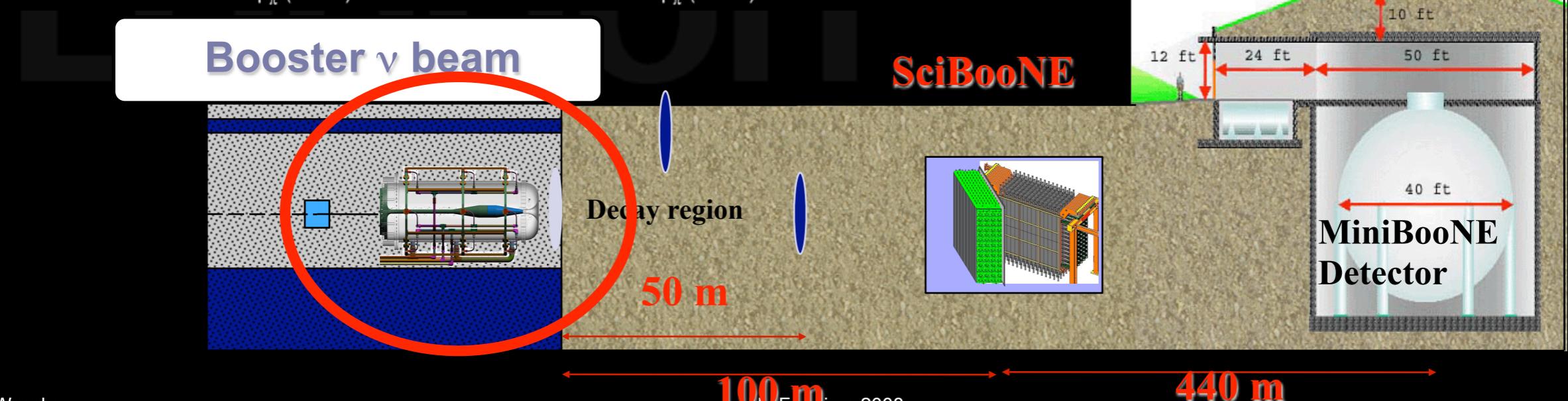


ν Flux Prediction

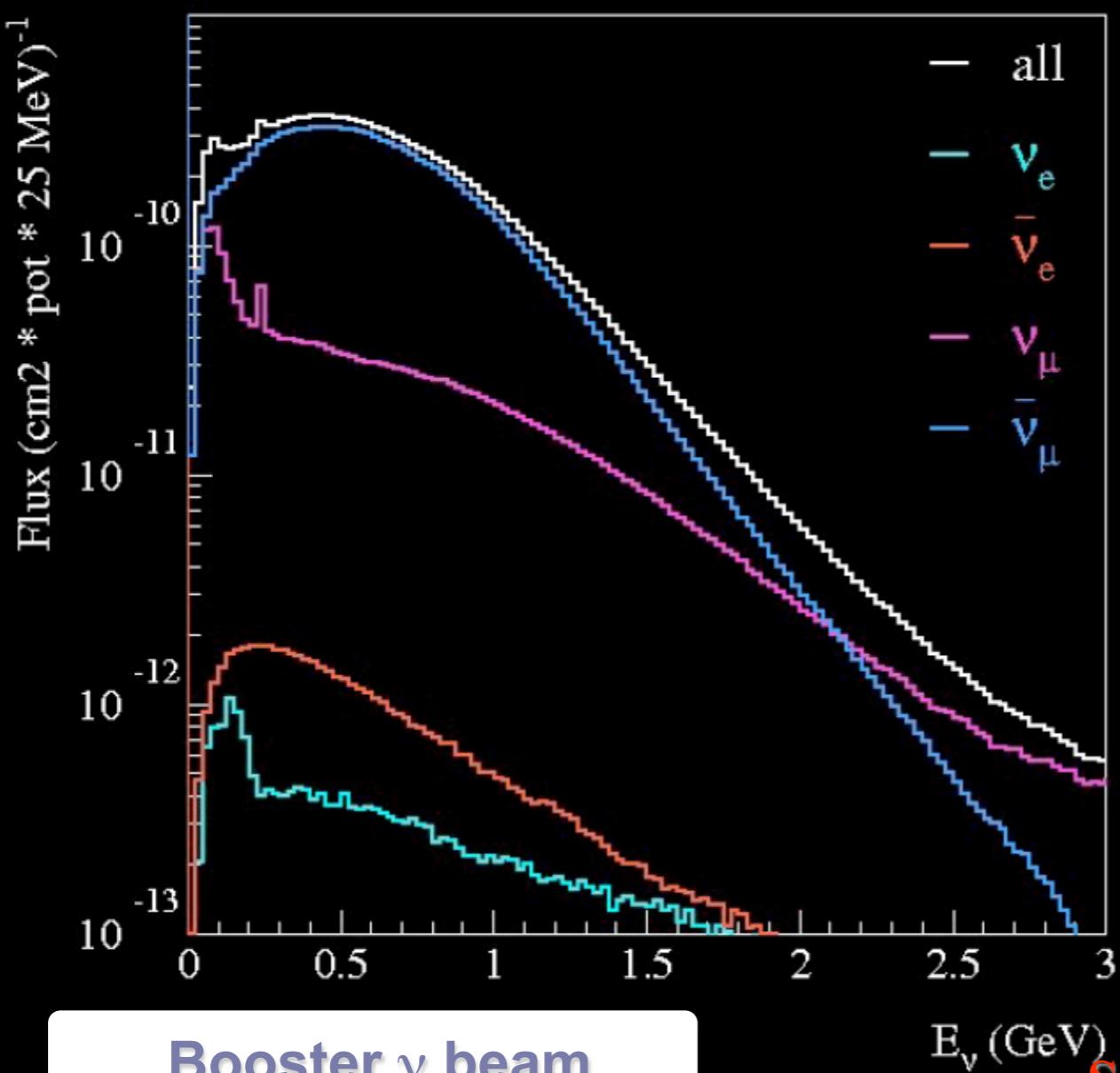
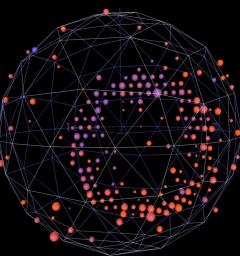


- External meson production data
 - E910 (BNL), HARP (CERN)
- Parametrisation of cross sections
 - Sanford-Wang for pions
 - Feynman scaling for kaons
- Now directly use HARP data to estimate flux uncertainties

arXiv:0806.1449 [hep-ex]

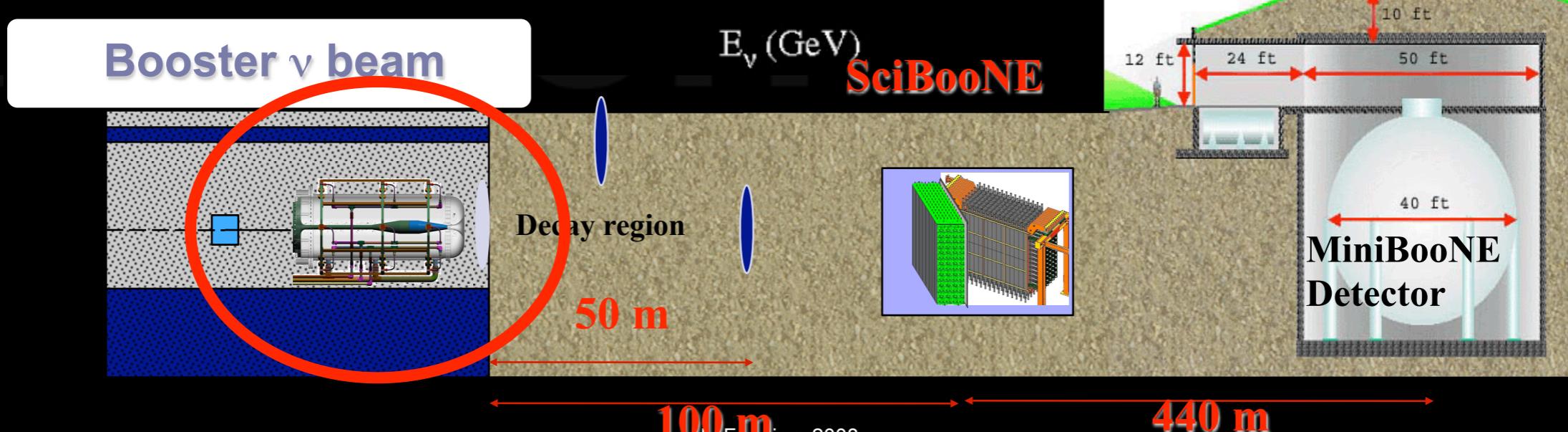


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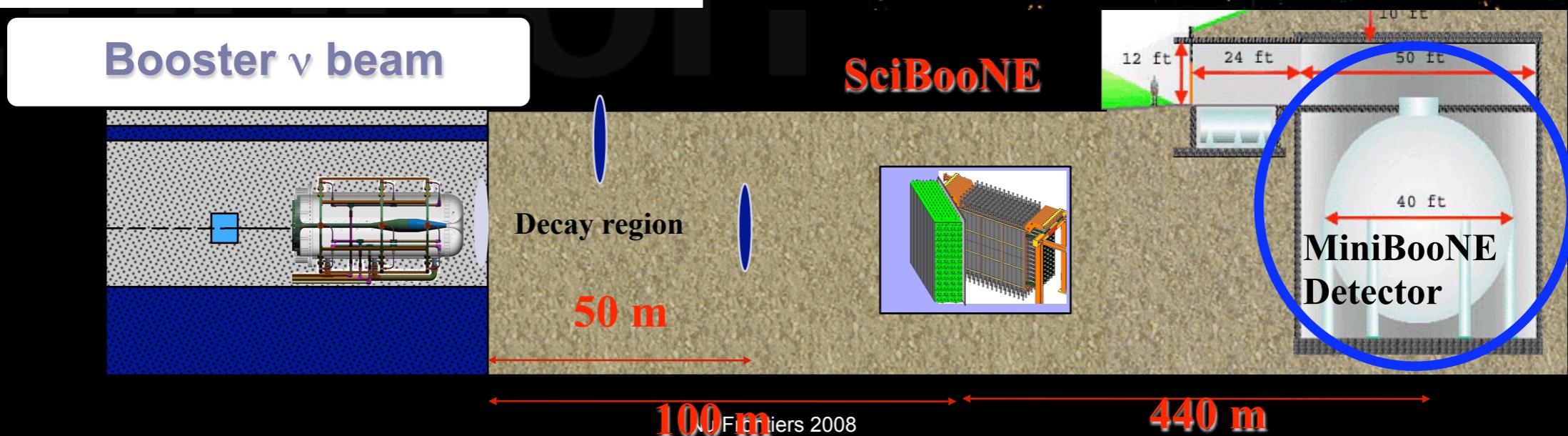
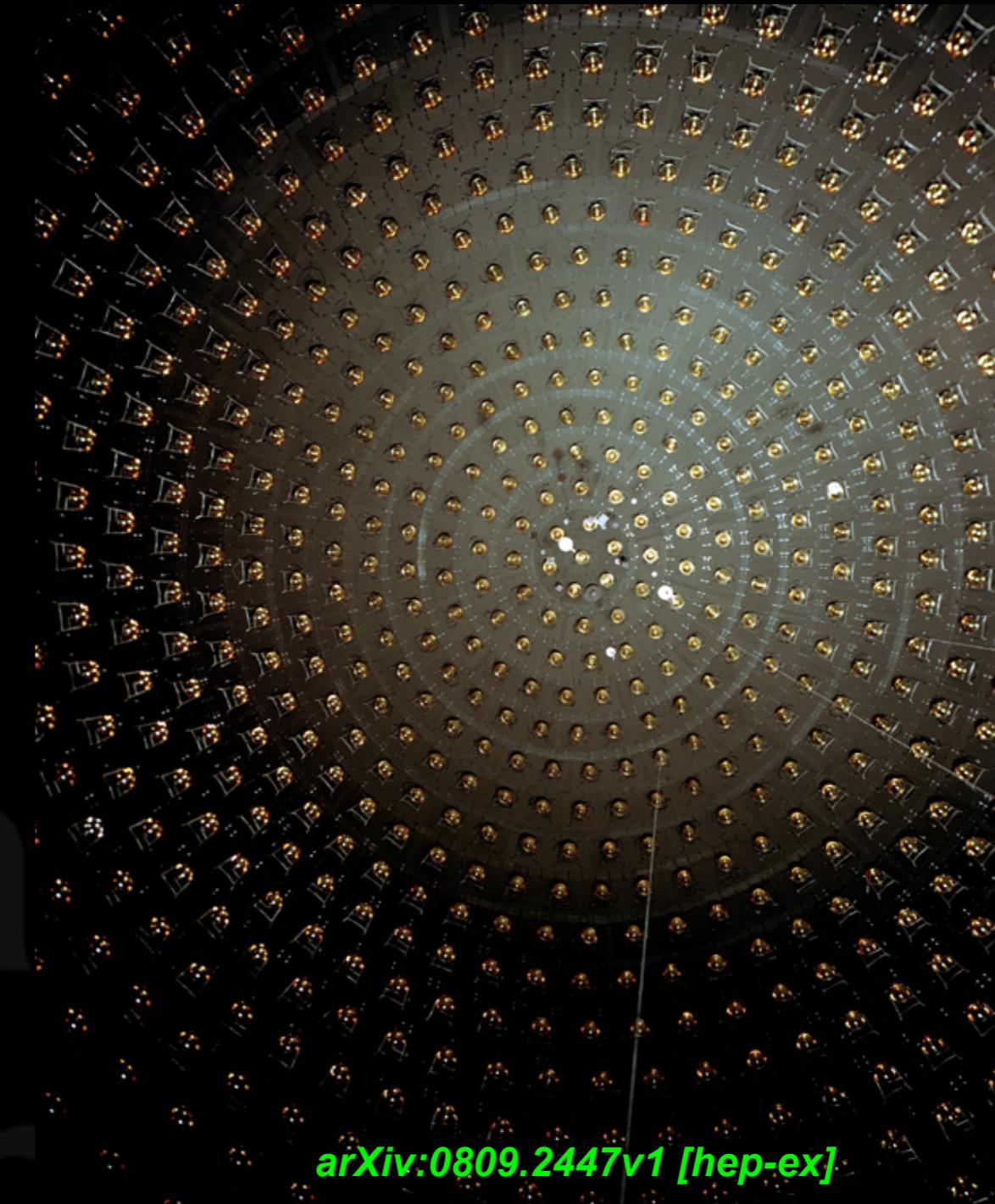
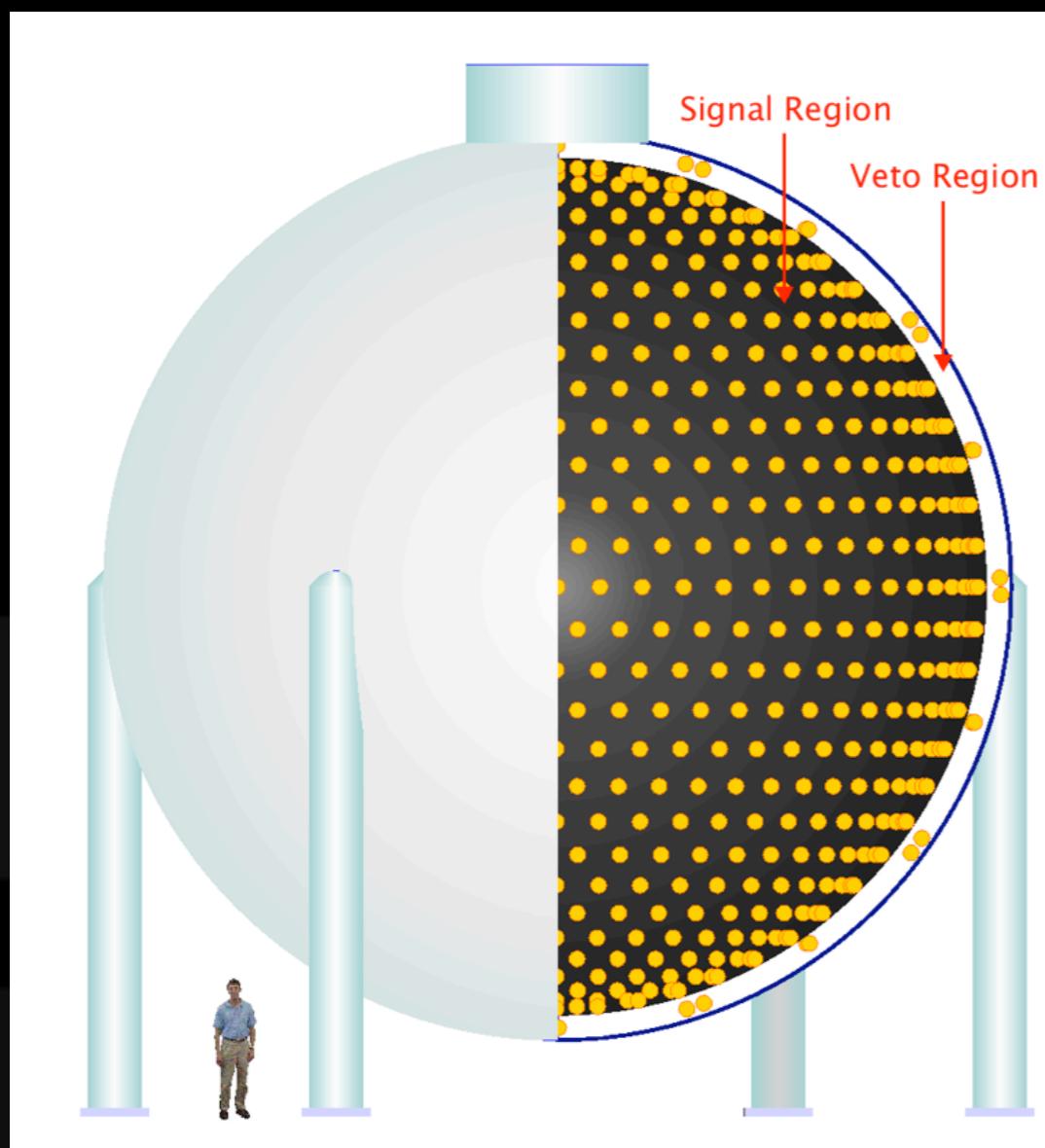
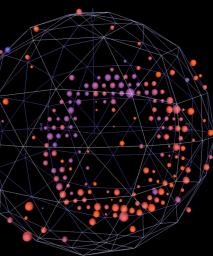


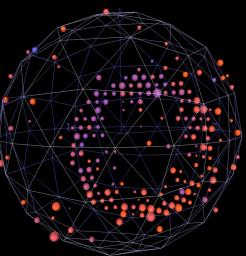
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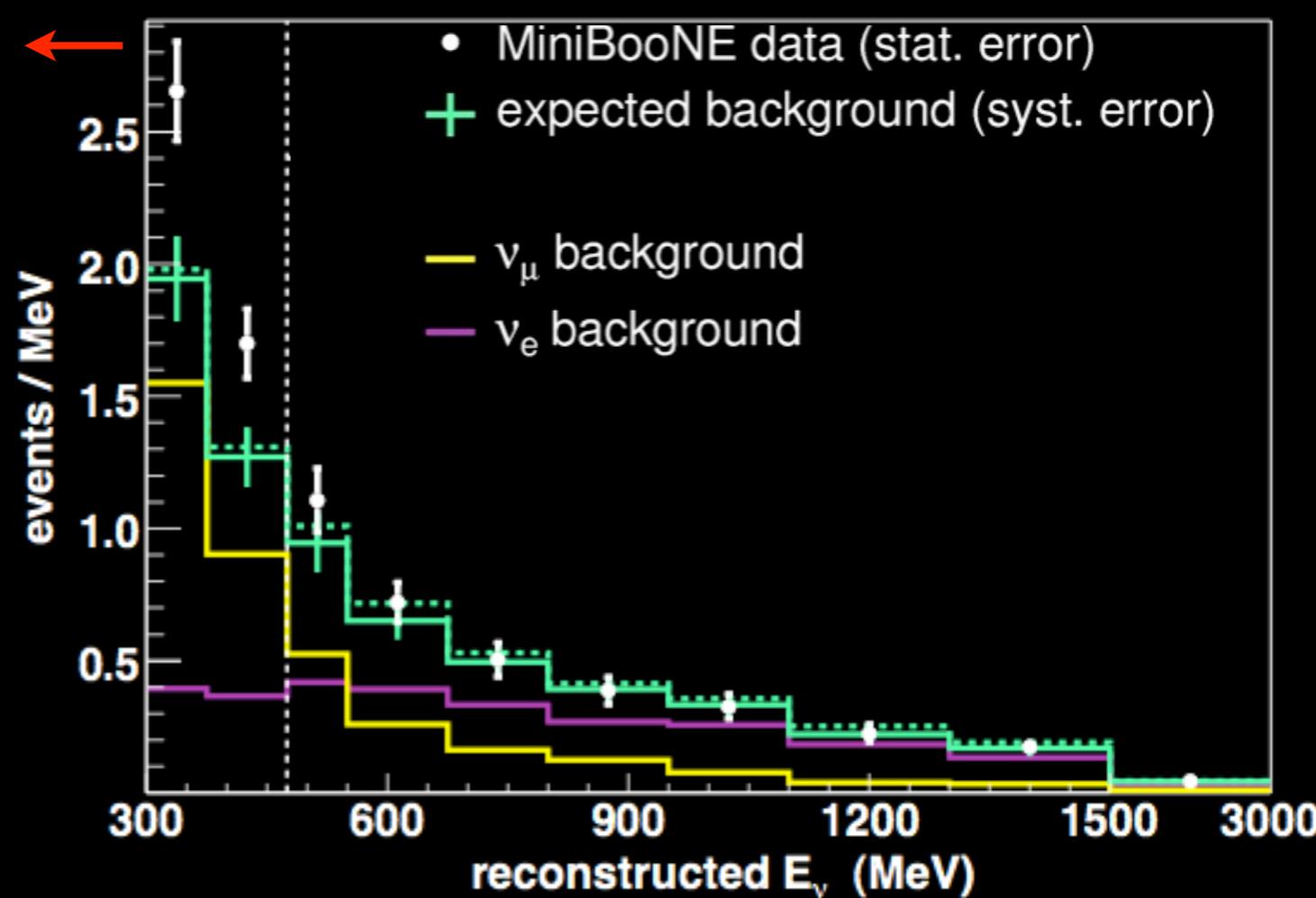
Detector

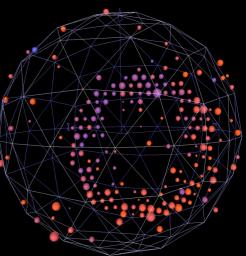




More data

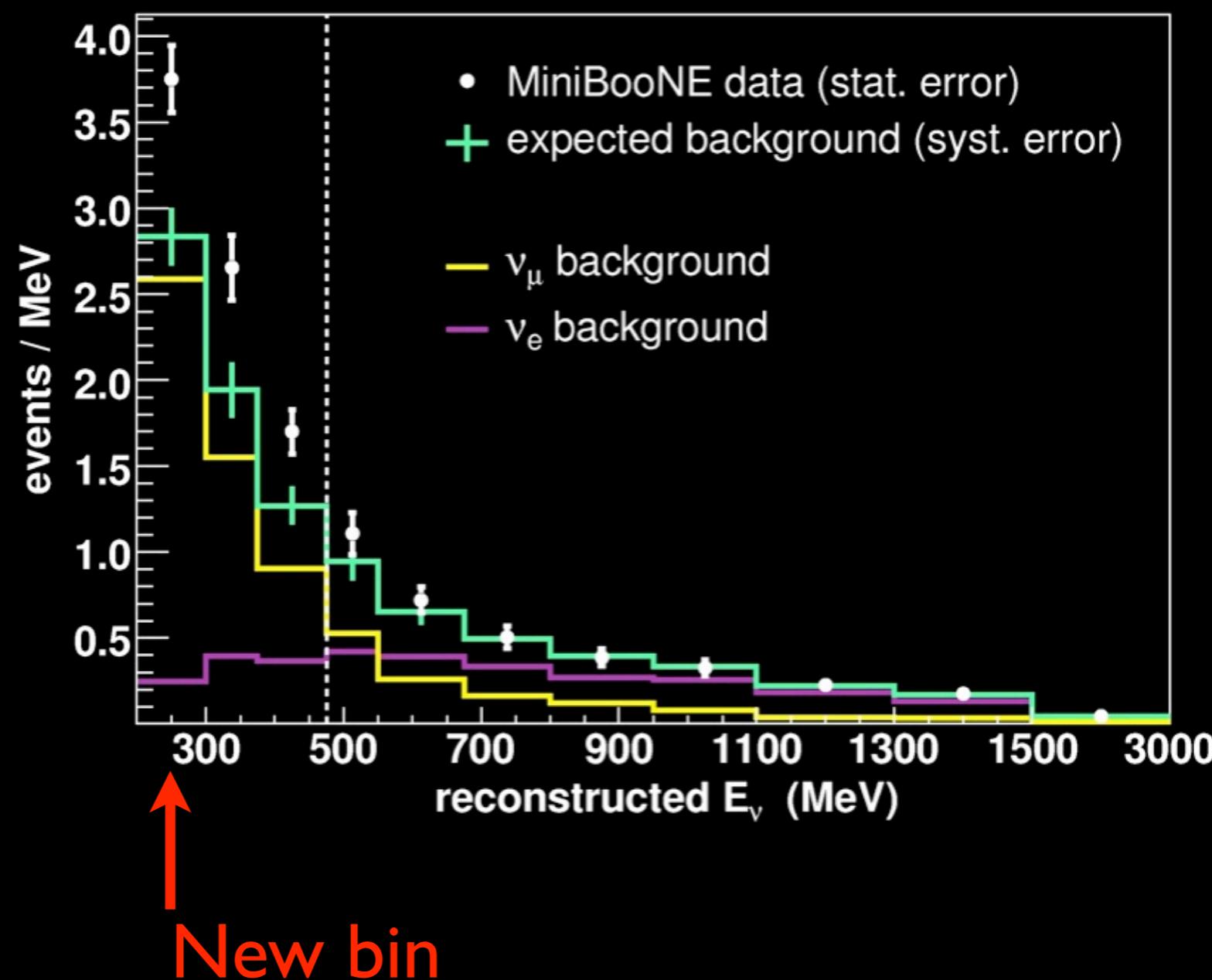
- More data always helps
- Extended threshold to lower energy
 - required extension of systematics
- Excess persists below 300 MeV
- Collected 0.84×10^{20} POT more during SciBooNE neutrino run
 - Excess persists in new data



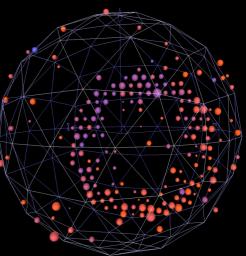


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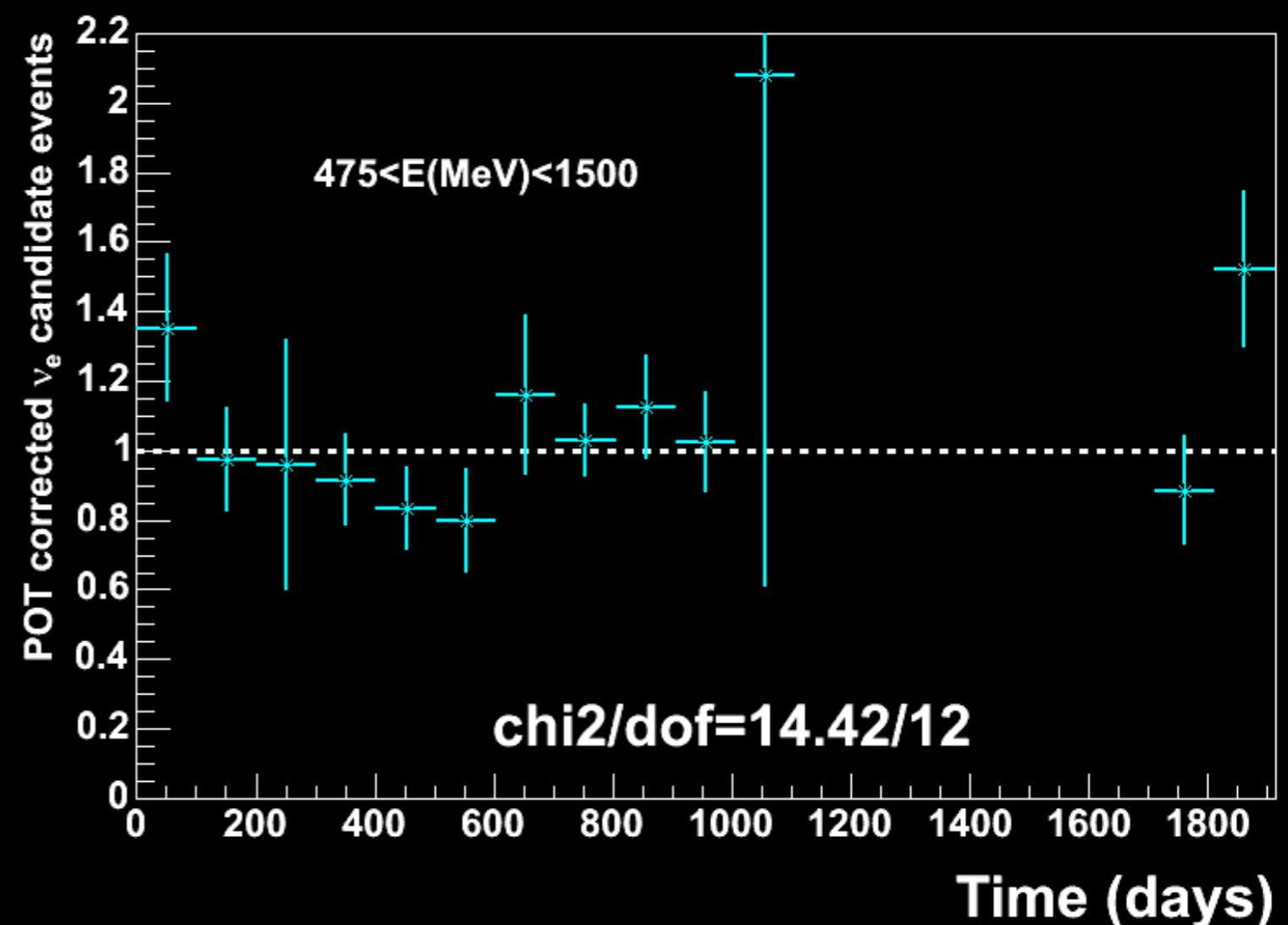
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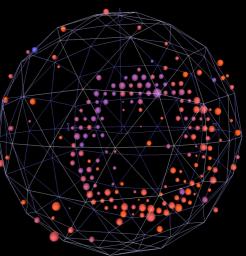


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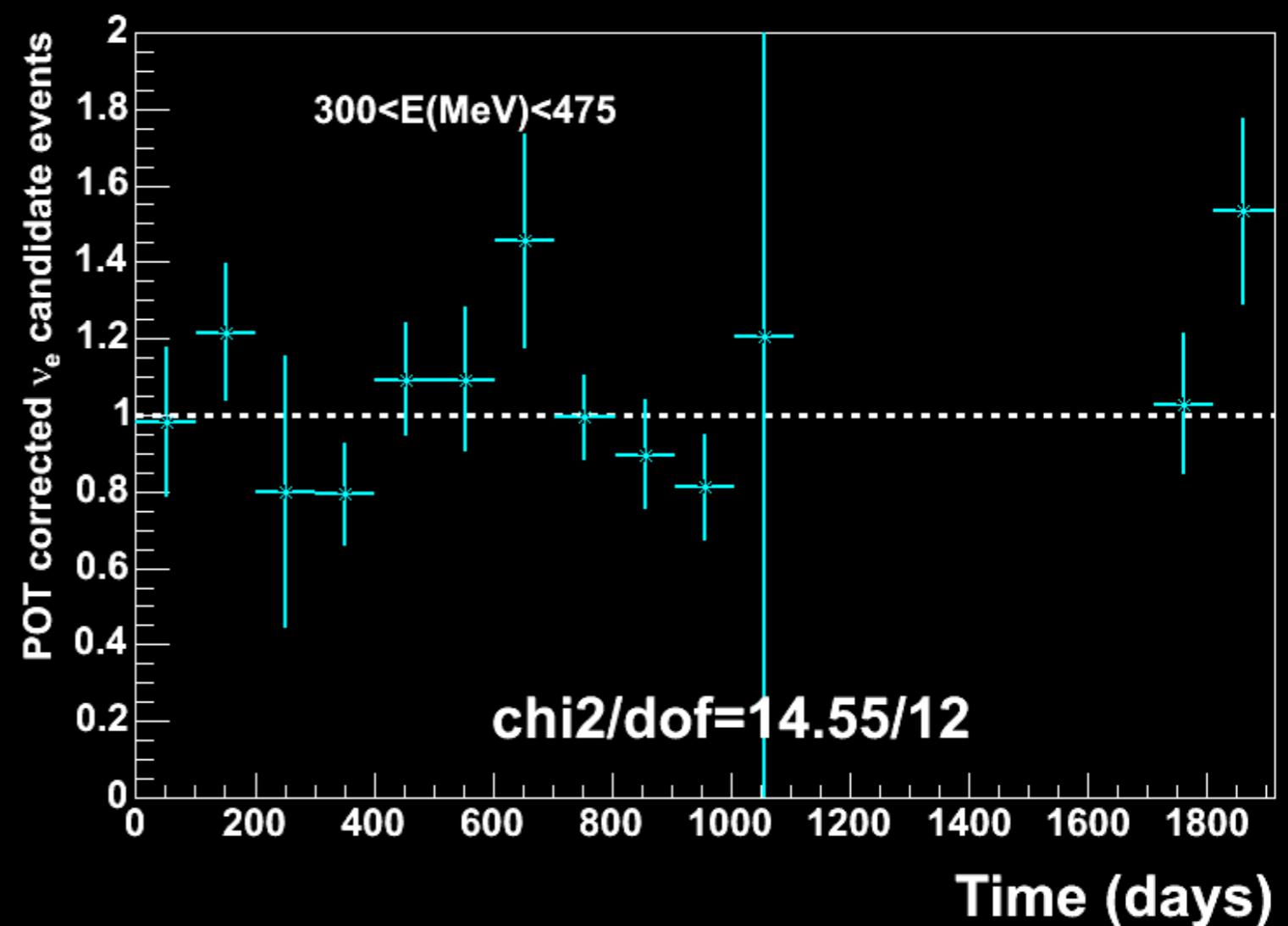
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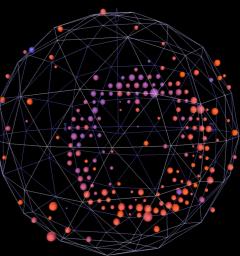


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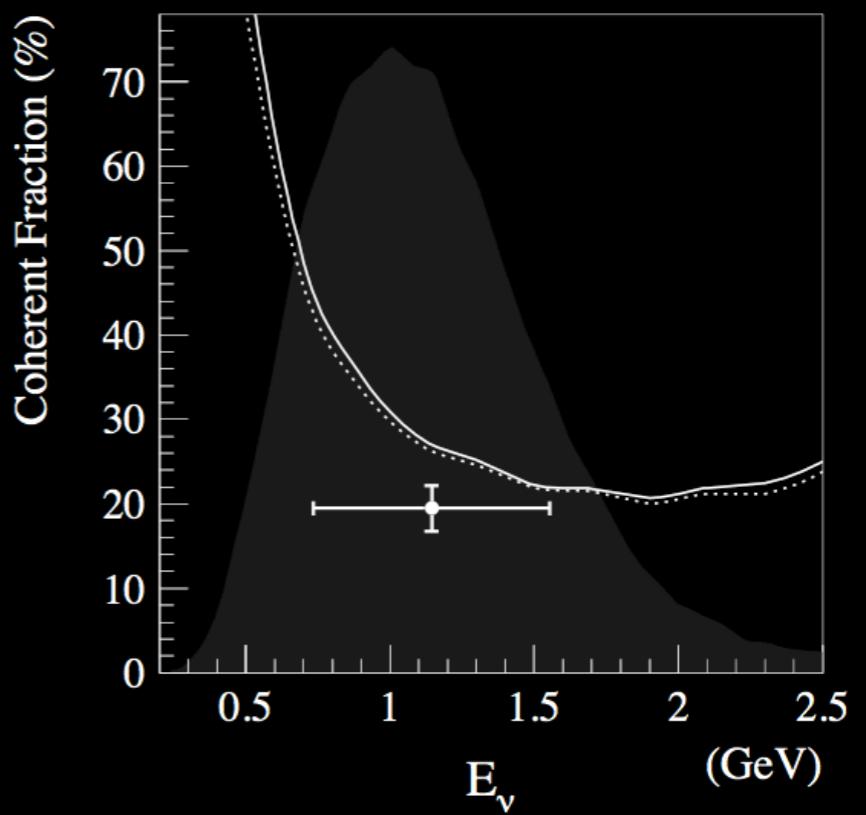
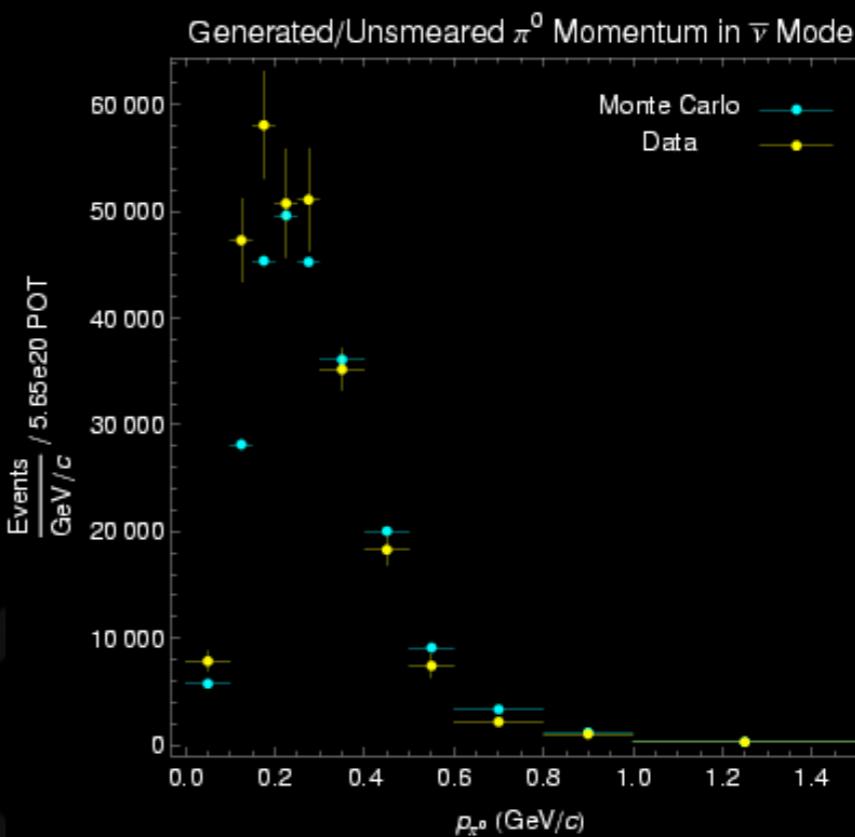
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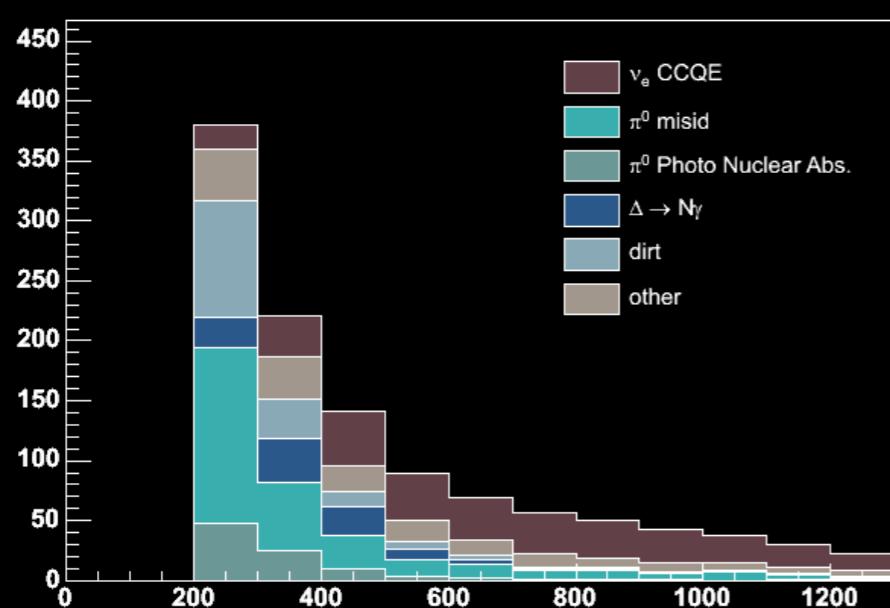
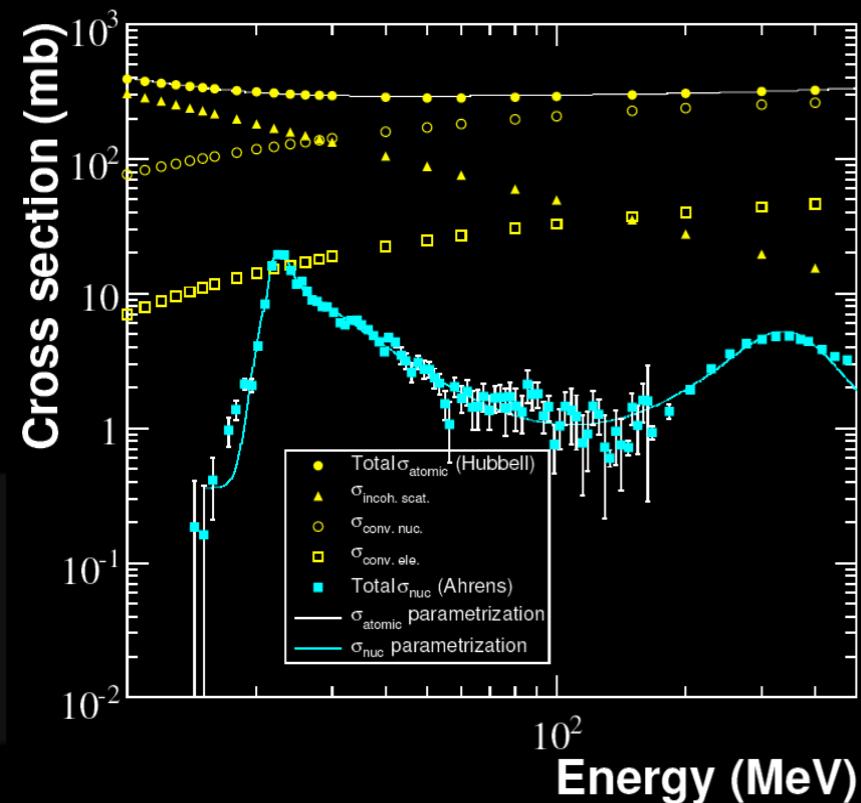
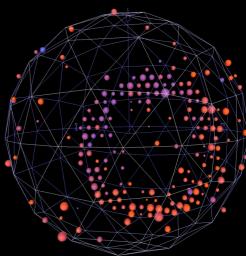
π^0 Backgrounds



- Complete redo of pi0 analysis
- Use in-situ measurement of NC coherent pion fraction
- Improvement of D-->Ng prediction
- Bottom line: small change in BG, slight increase in uncertainty

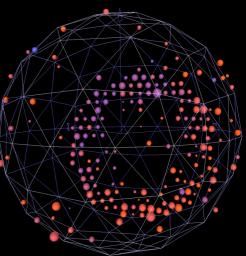


Photonuclear Process

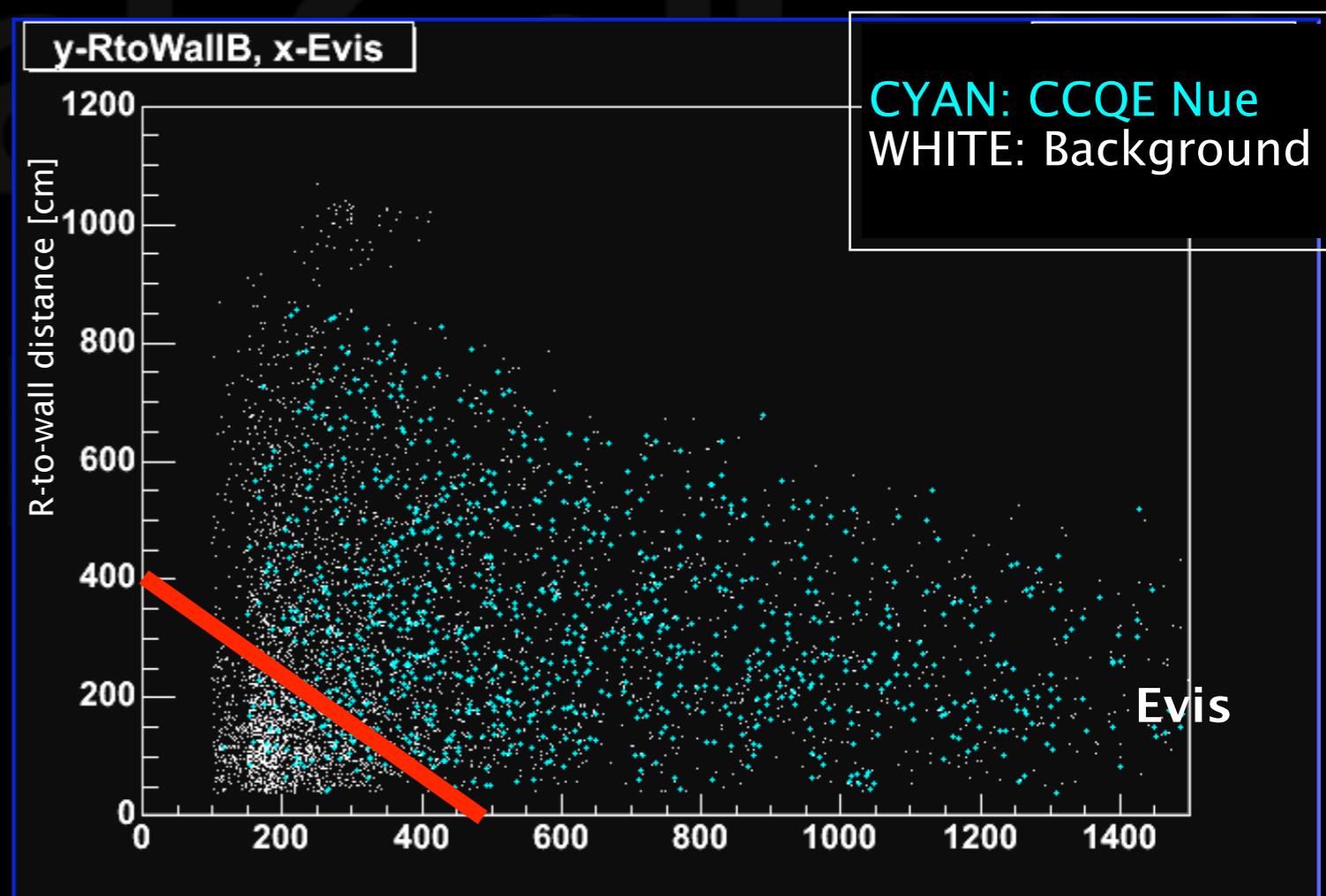
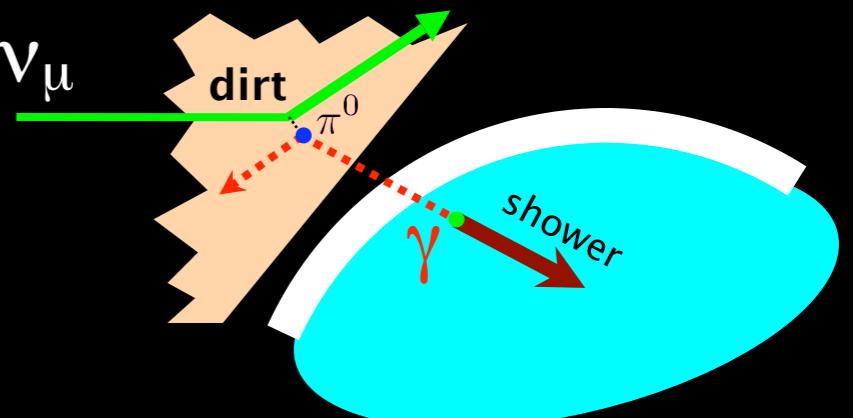


- Complete overhaul of simulation of hadronic processes in detector
- Found new source of BG events: photonuclear process
- Can remove one photon from π^0 decay
- Bottom line: Adds 65 nue background events (200-475 MeV)

Dirt Backgrounds

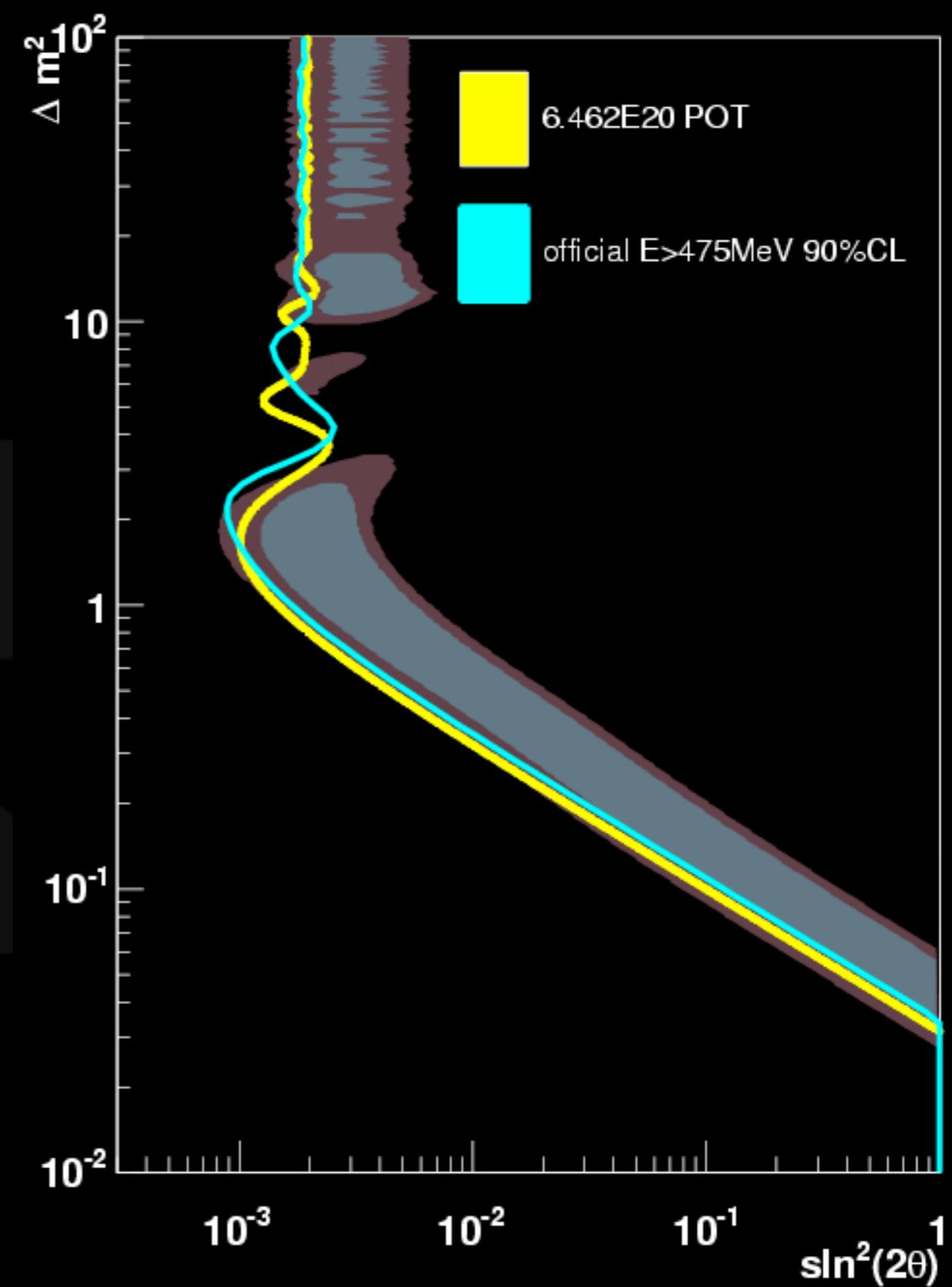
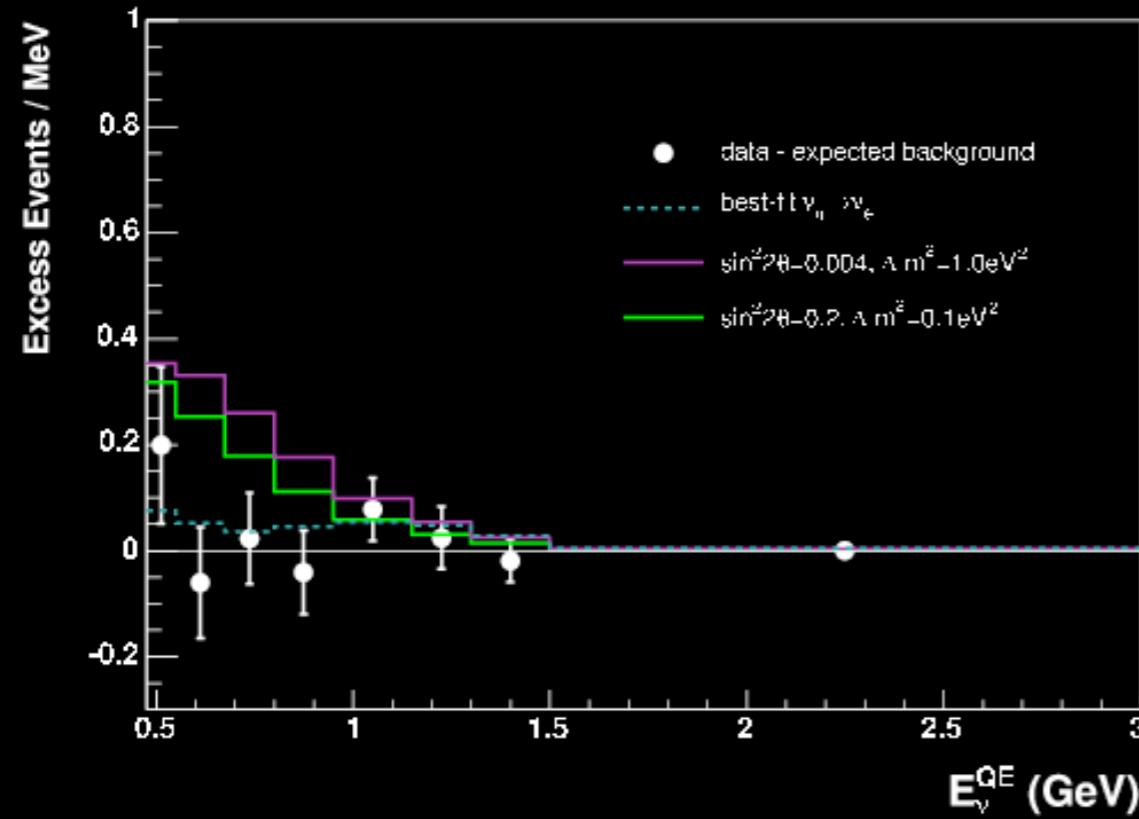
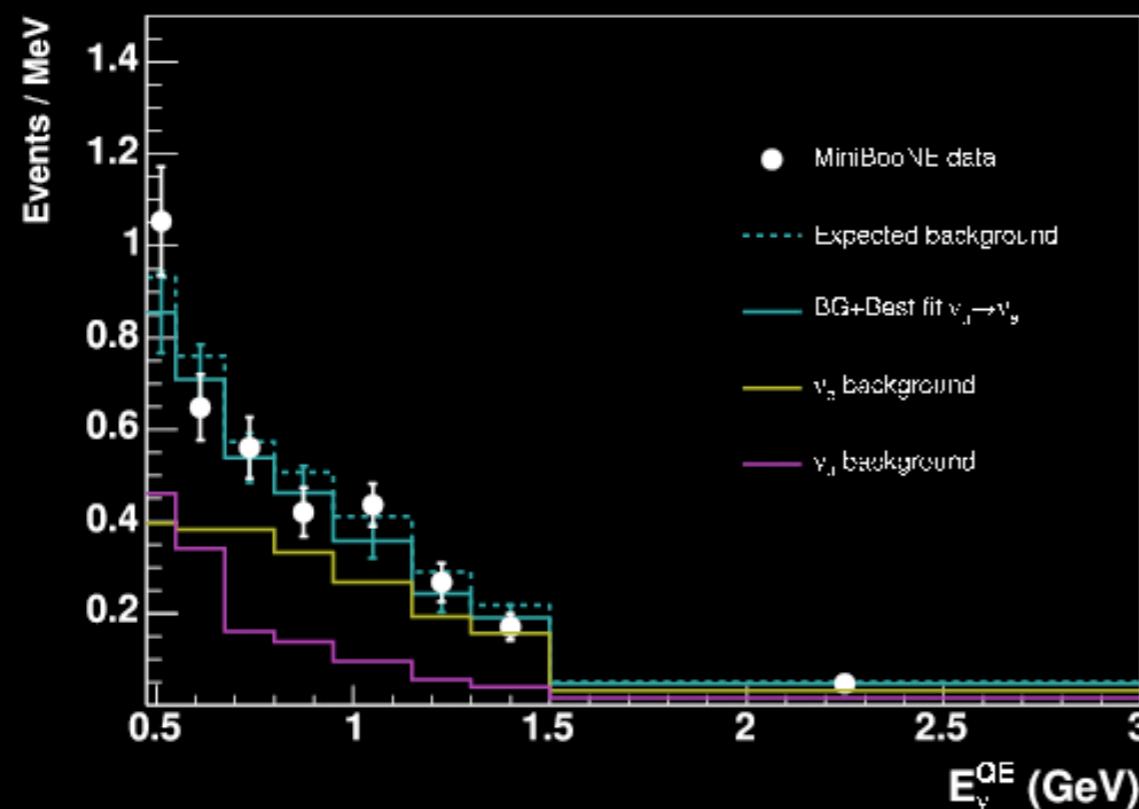
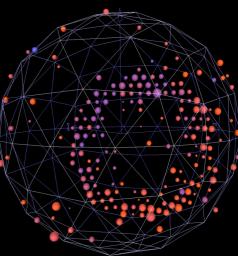


- “Dirt” events are neutrinos interacting outside the detector and sending secondary particles into the fiducial volume
 - Neutral particles can pass through veto
 - Use energy-distance cut to remove most dirt backgrounds



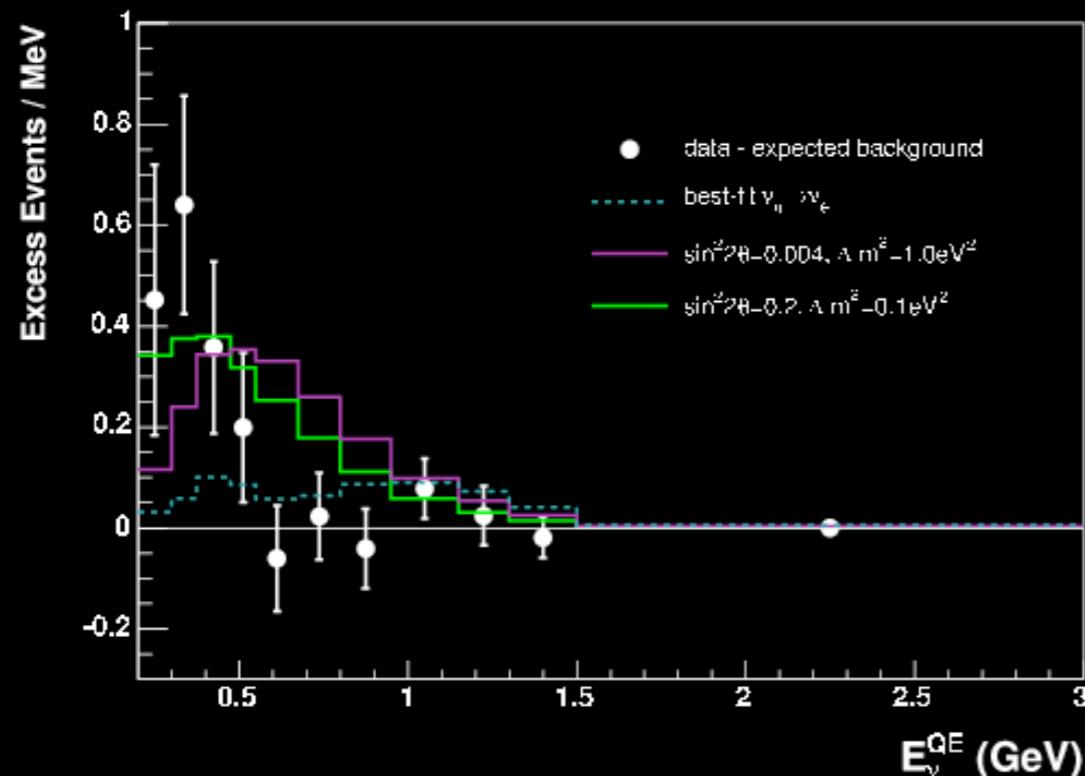
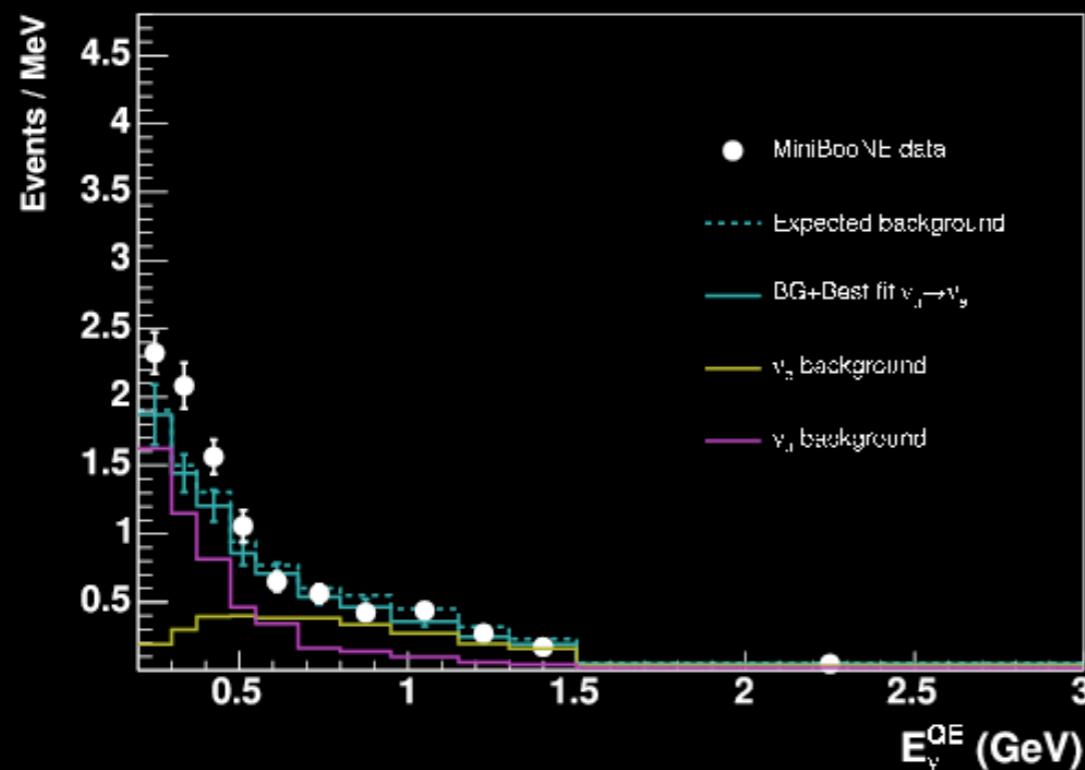
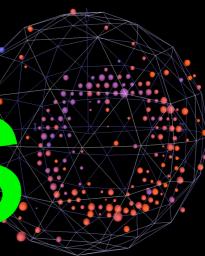
100

New ν_e Result



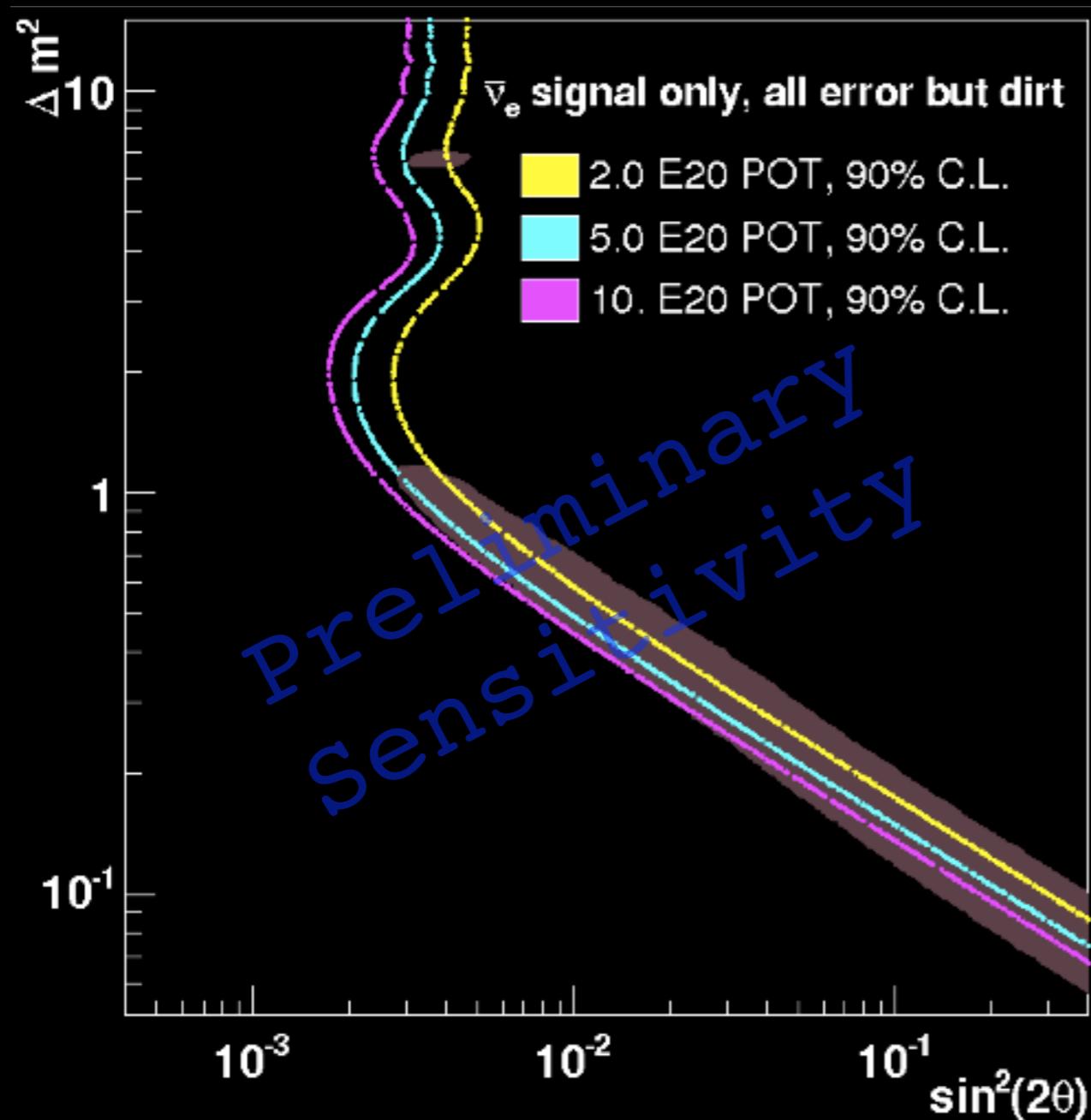
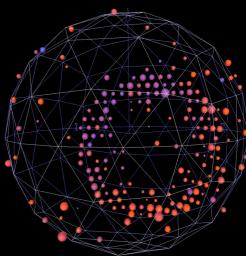


New Low Energy Excess



- Low energy excess has not vanished!
- Oscillation energy region unaffected
- New value: 128.8 ± 43.4 ν_e events in the energy range 200-475 MeV
- Shape of excess is not consistent with 2- ν oscillation hypothesis
- Hypothesis comparisons being processed now

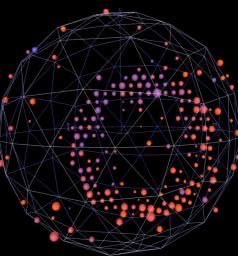
$\bar{\nu}_e$ appearance



- Goal is to search for $\bar{\nu}_e$ appearance with sensitivity similar to ν_e appearance search
- The box has been opened!

*Fermilab seminar announcing
final result Dec XX!*

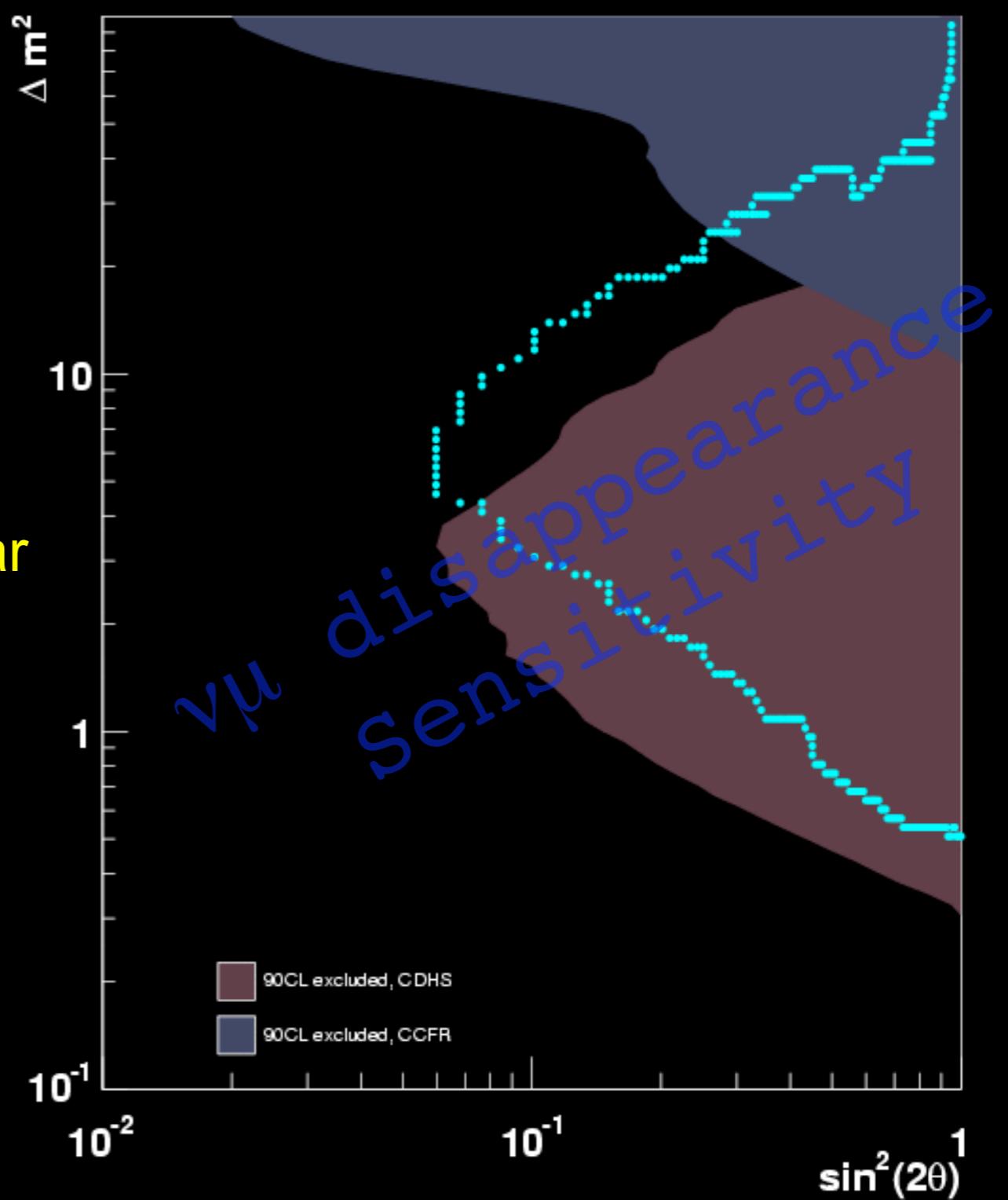
ν_μ disappearance



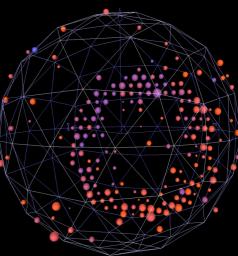
- With one detector, compare $E\nu$ data to MC and look for shape distortions
- MiniBooNE alone has significant reach in sensitivity
 - Analysis with SciBooNE as near detector in progress
- Hide Tanaka, Sunday
- Also search for $\bar{\nu}_\mu$ disappearance

Imperial
London

Fermilab seminar announcing
final result Oct 31

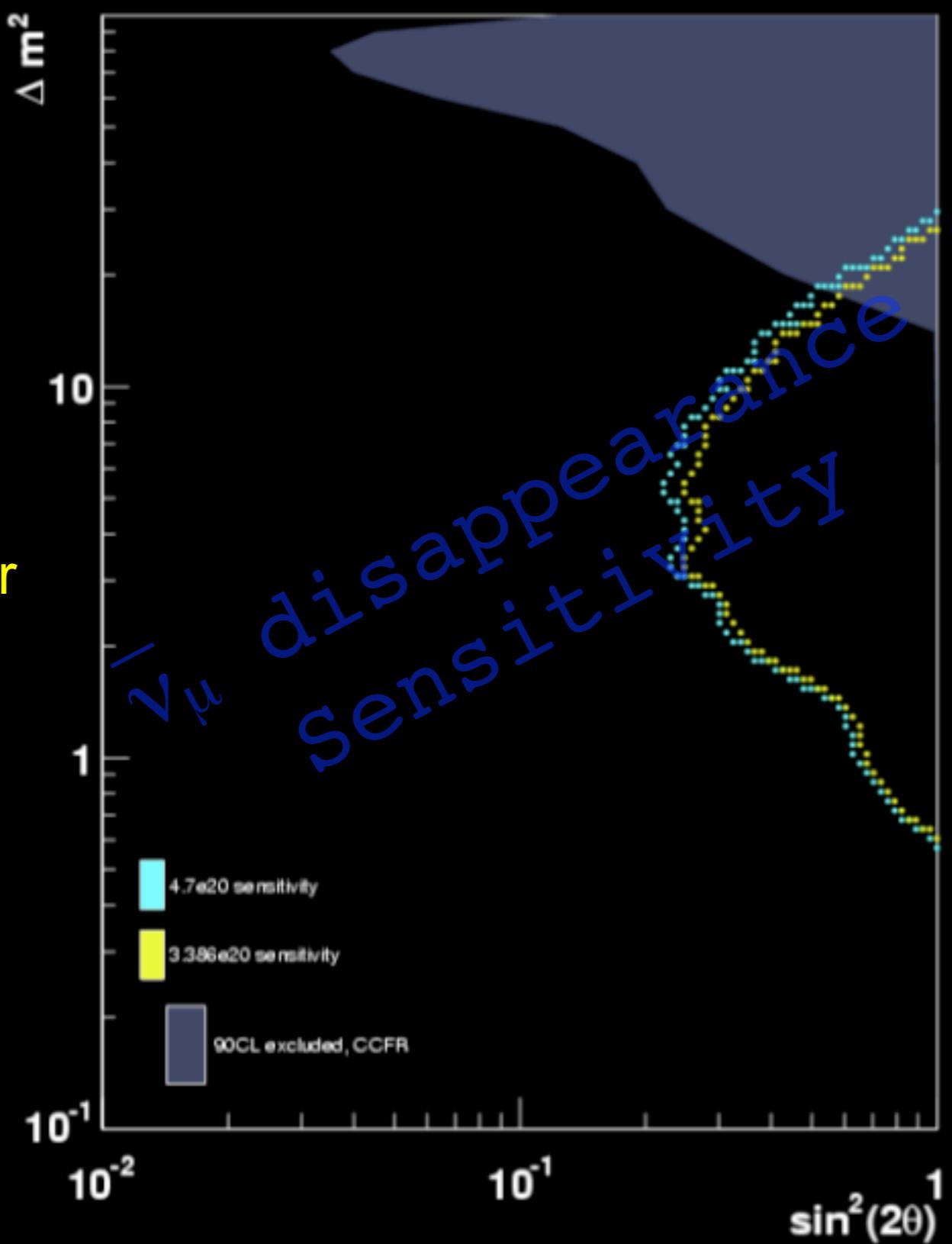


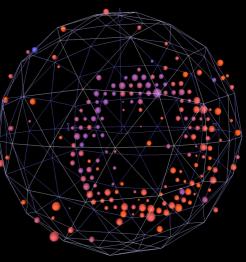
ν_μ disappearance



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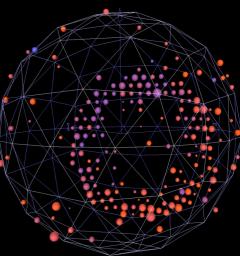


Things I skipped

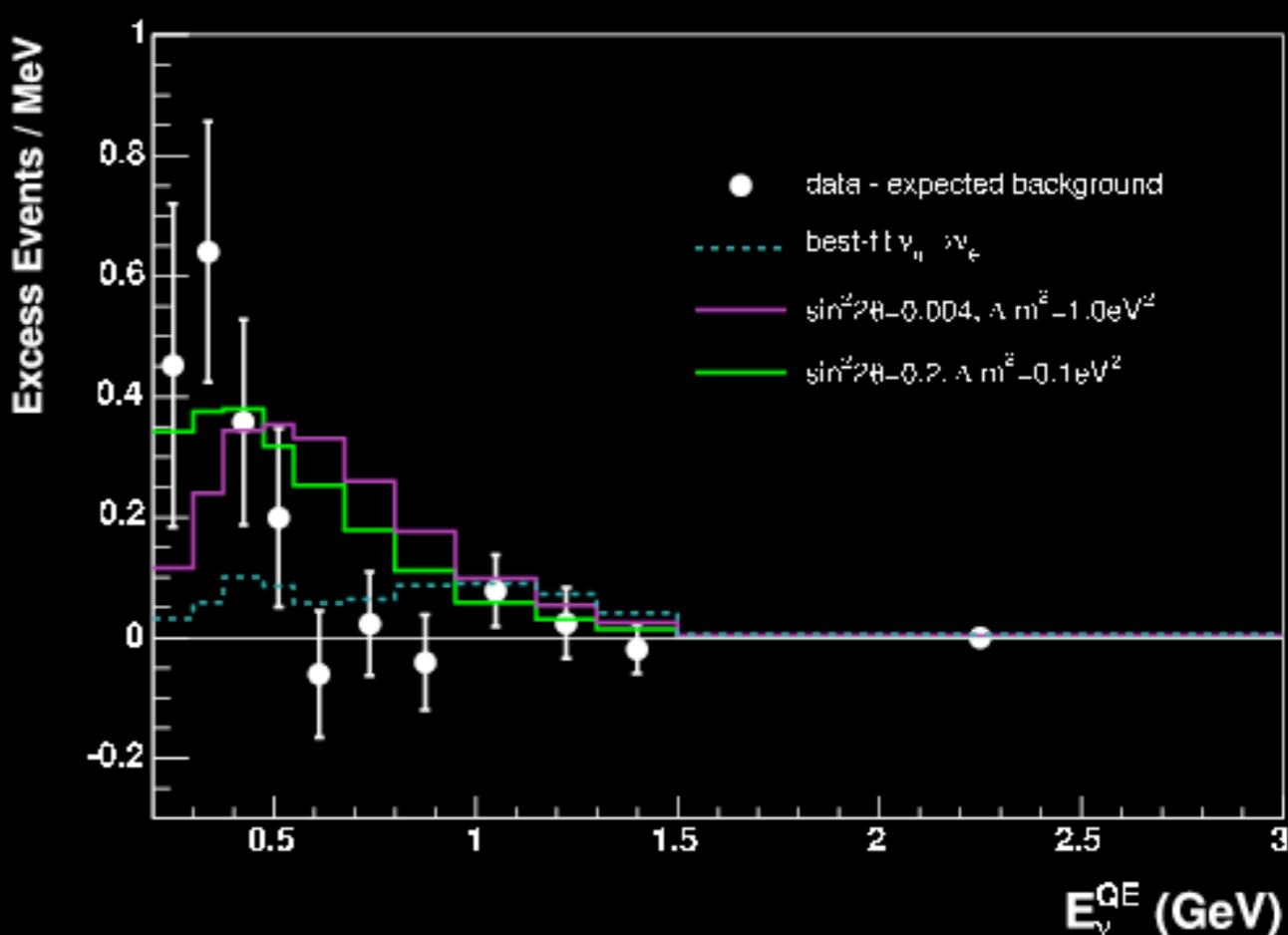
- NuMI
- BDT results
- Many cross section analyses

Imperial College
London

Summary



- MiniBooNE's low energy excess is real!
- Source of events is under investigation
- nuebar appearance results coming out soon
- Completes the true test of LSND oscillation hypothesis
- numu and numubar disappearance results soon

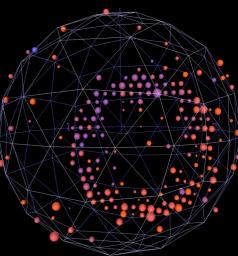




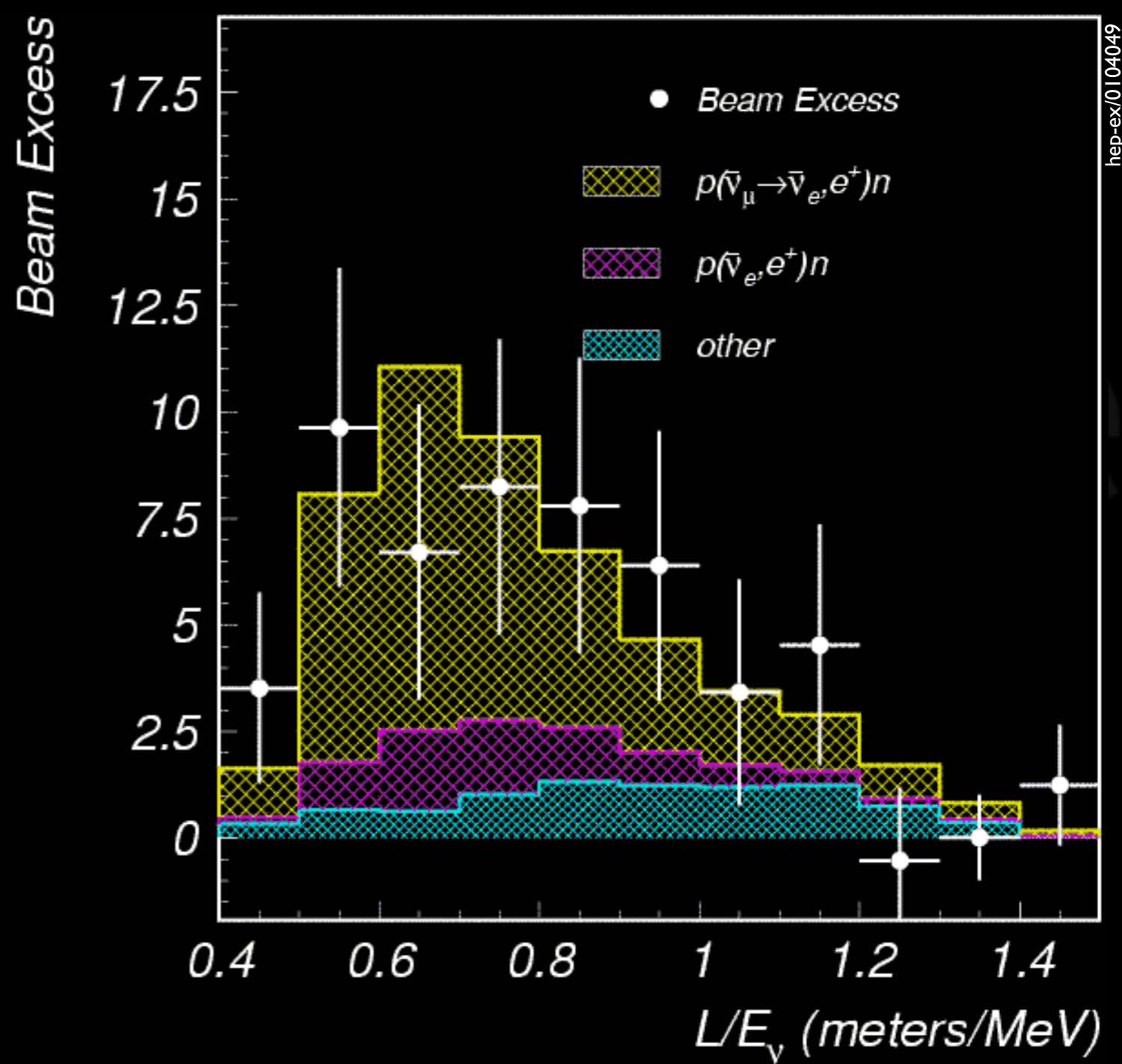
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Backups

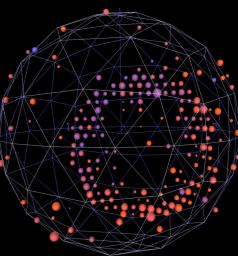
LSND Signal



- Clean experimental signature
 - Stopped pion neutrino source
 - Delayed coincidence detection signal
- excess: $87.9 \pm 22.4 \pm 6.0$
- Interpreted as 2ν oscillation
- $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e) = 0.26\%$



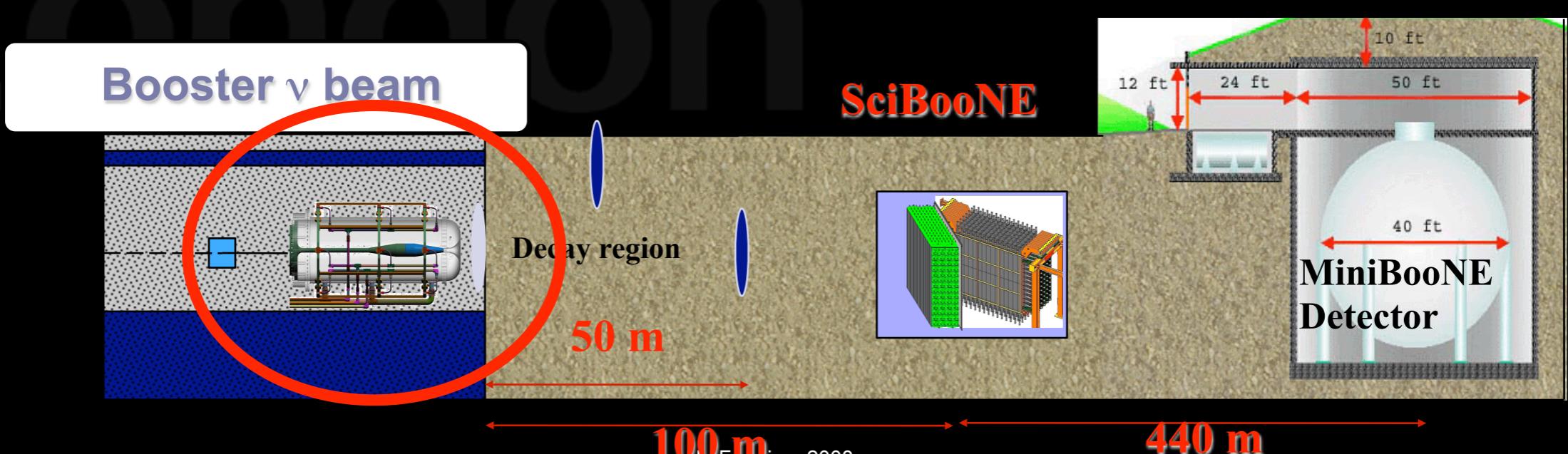
Target & Horn



POT uncertainty <2%

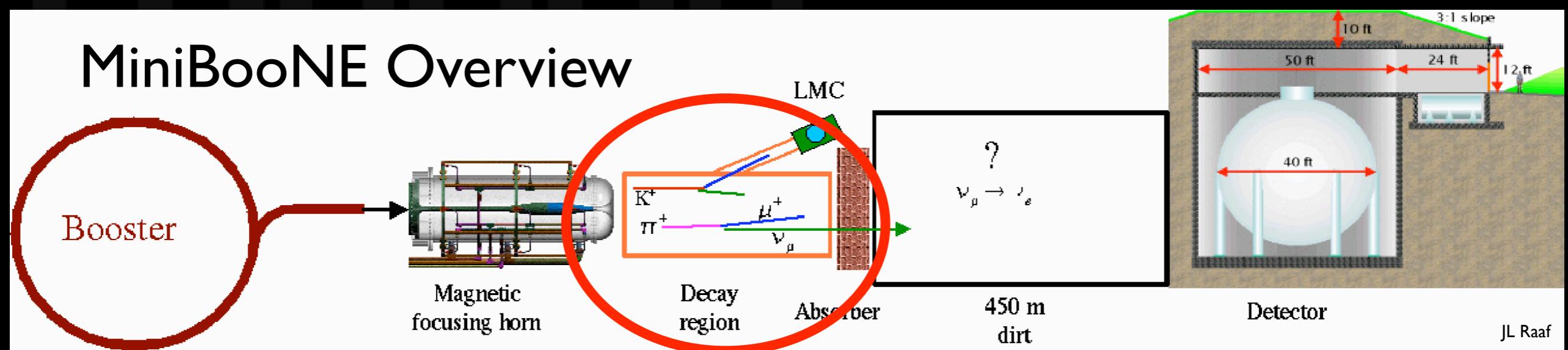
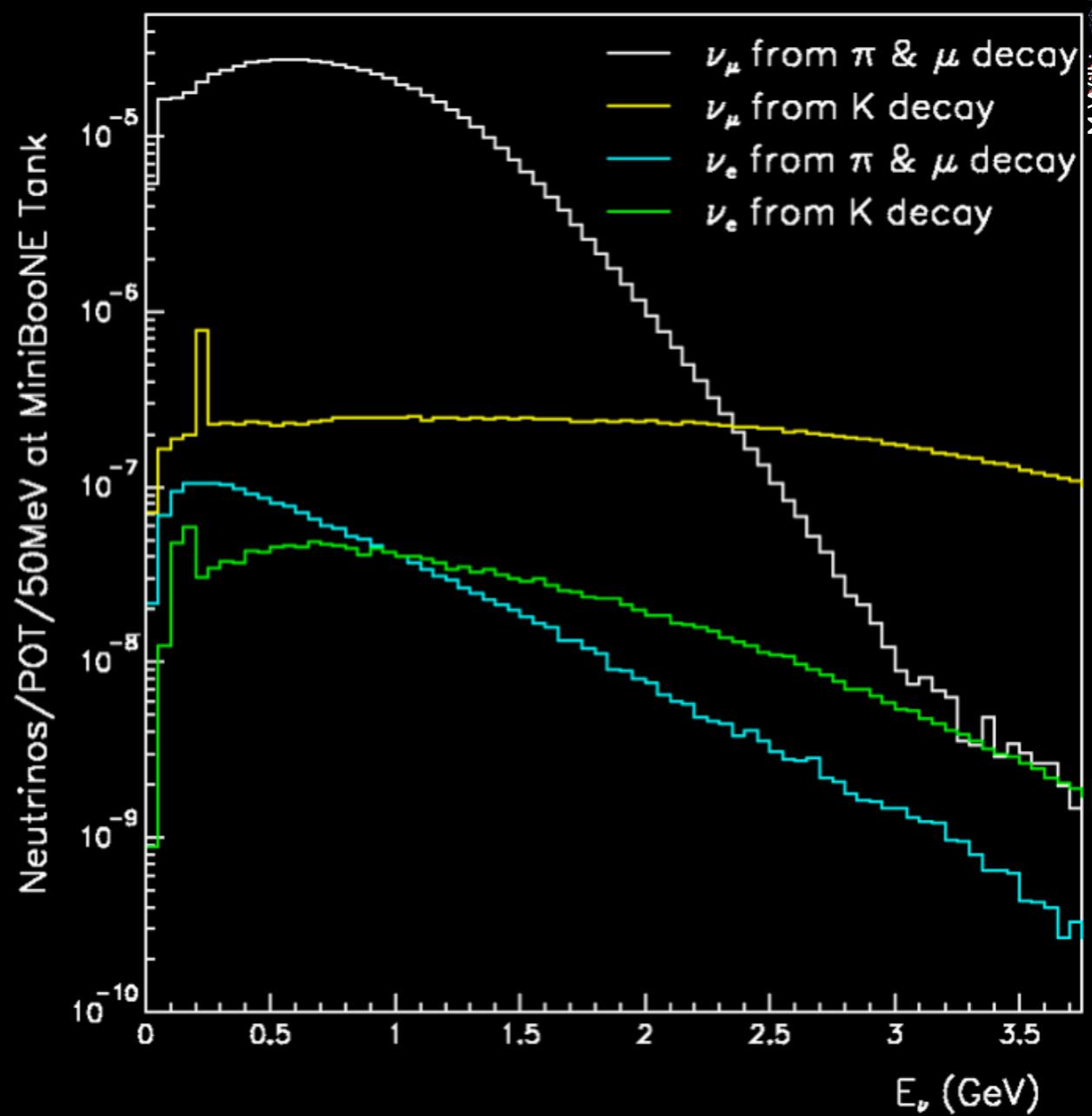


Main components of Booster Neutrino Beam (BNB)
(96M and 179M+ pulses)

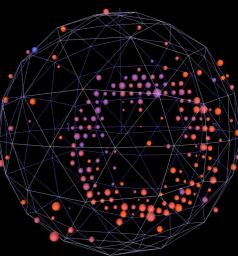


ν Flux

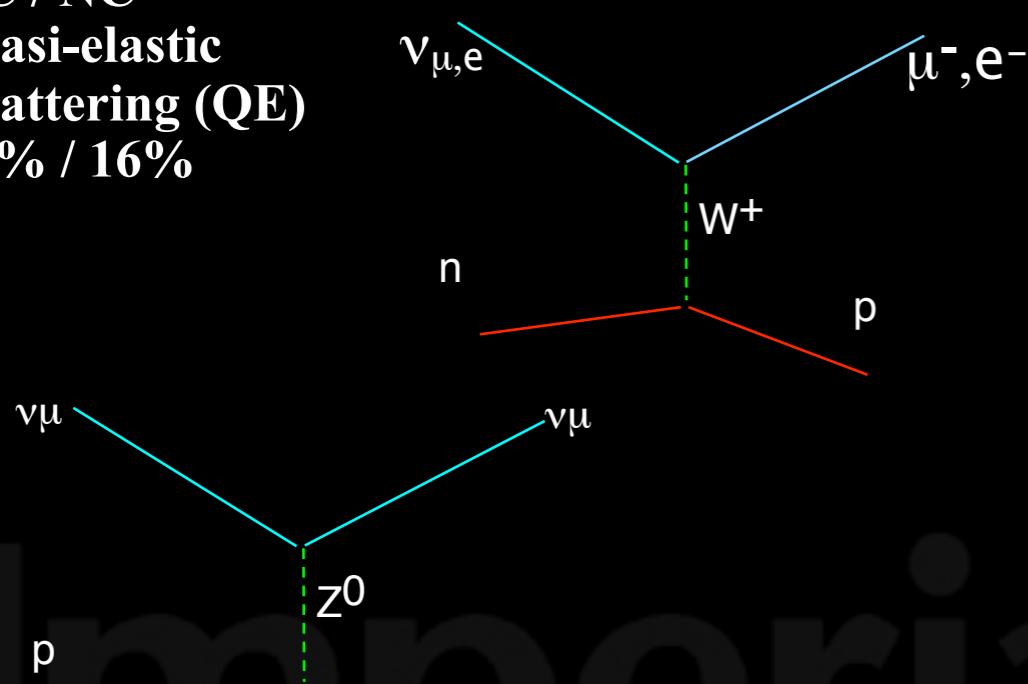
- 99.5% pure muon flavour
- 0.5% intrinsic ν_e
- Constrain ν_e content with ν_μ measurements



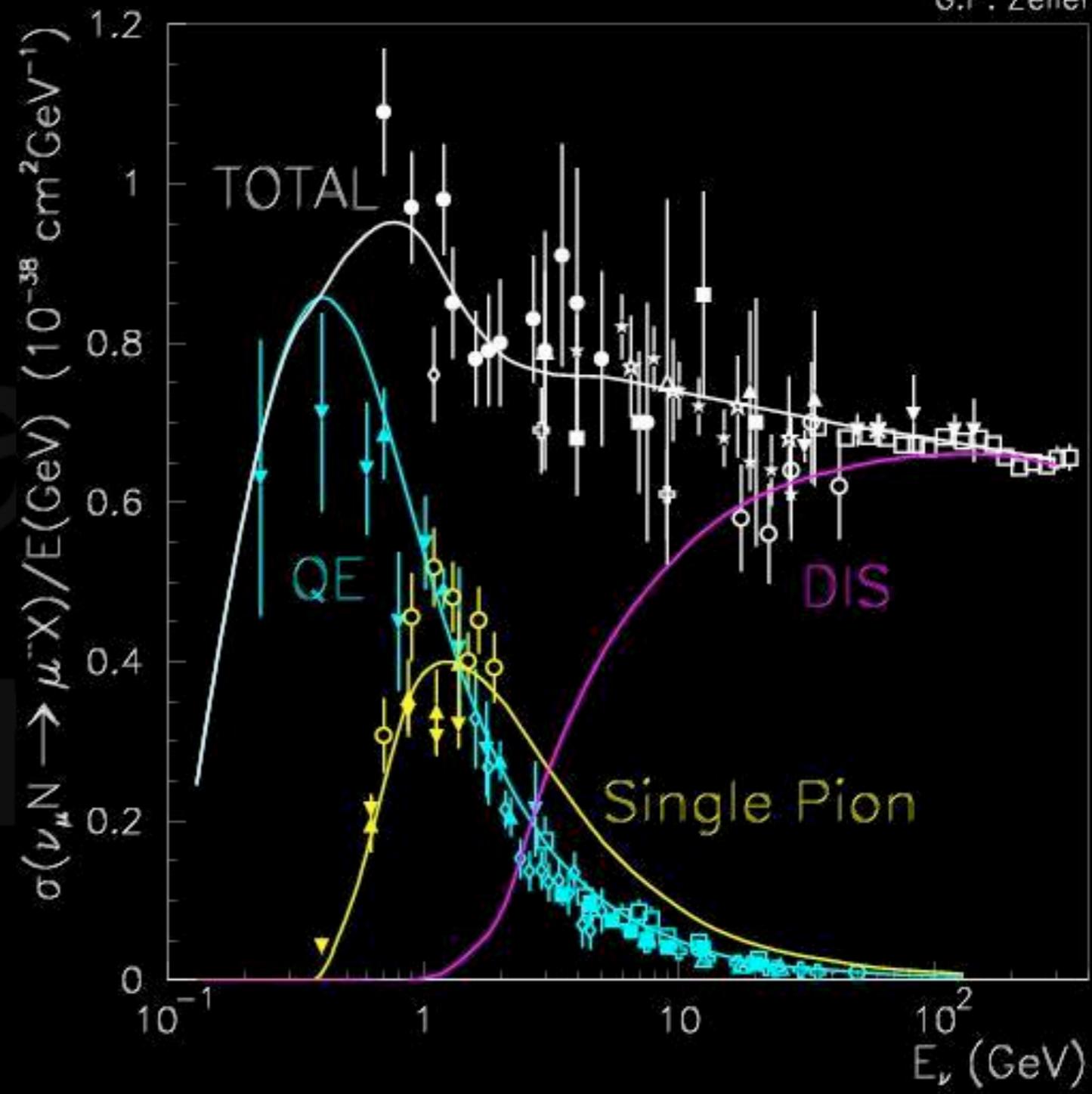
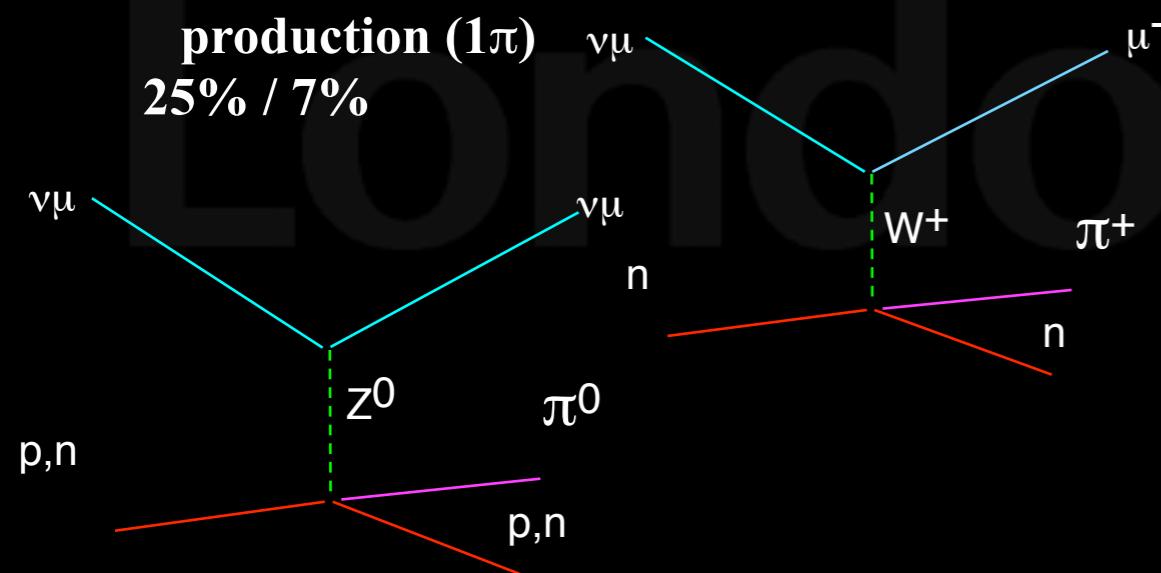
Cross Sections



CC / NC
quasi-elastic
scattering (QE)
42% / 16%

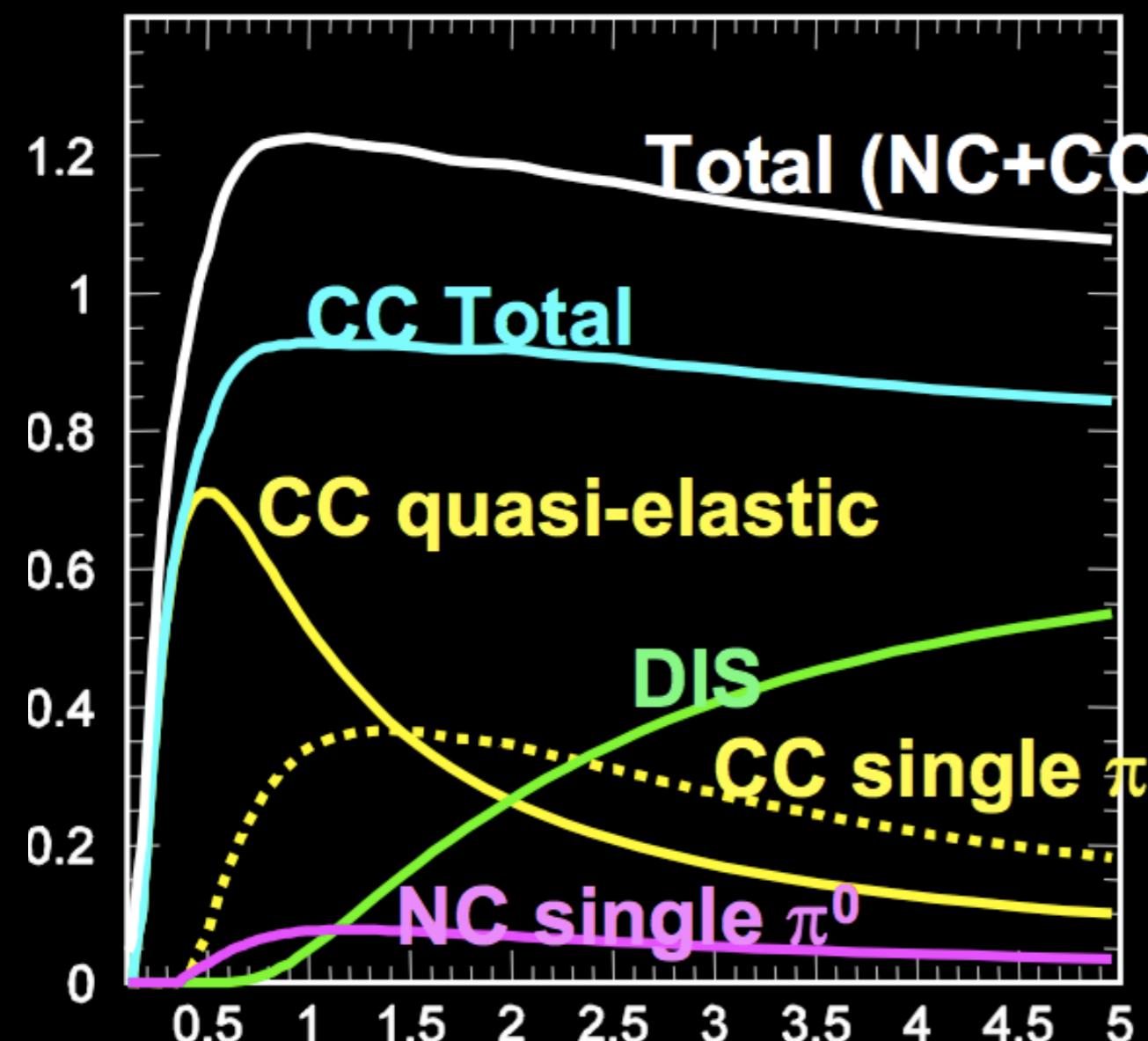


CC / NC
resonance
production (1π)
25% / 7%



σ_ν predictions

σ/E ($10^{-38} \text{cm}^2/\text{GeV}$)



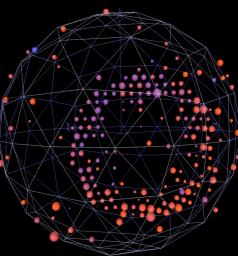
Target:
CH

E_ν (GeV)

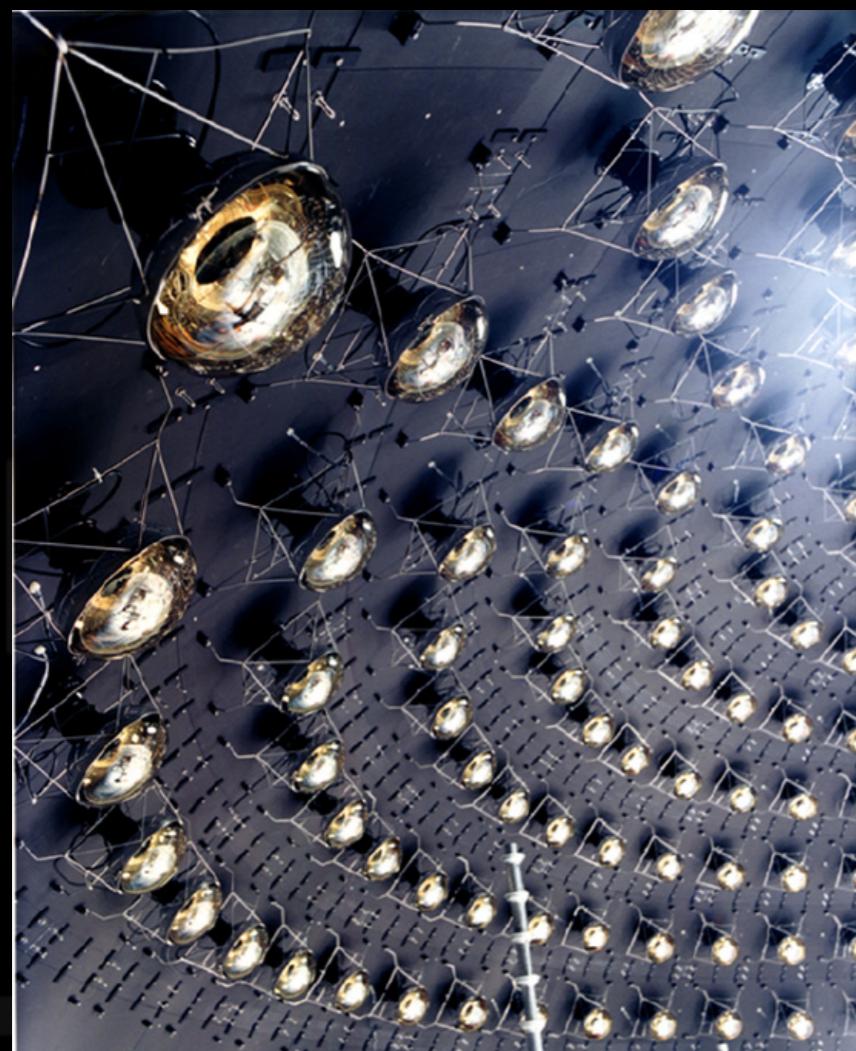
NEUT Monte Carlo

- QE
 - Llewellyn-Smith
 - $M_A = 1.1 \text{ GeV}/c^2$
 - Non-dipole Vector FF (BBBA)
 - Rel. Fermi Gas (Smith & Moniz)
 - $p_F = 217 \text{ MeV}/c$, $E_B = 27 \text{ MeV}$
- Resonant π
 - Rein & Sehgal
 - $M_A = 1.1 \text{ GeV}/c^2$
- Coherent π
 - Rein & Sehgal w/ lepton mass corrections
- DIS
 - GRV98 w/Bodek & Yang correction
- Nuclear effects:
 - Formation zone & nucleon final state interactions

Track Reconstruction



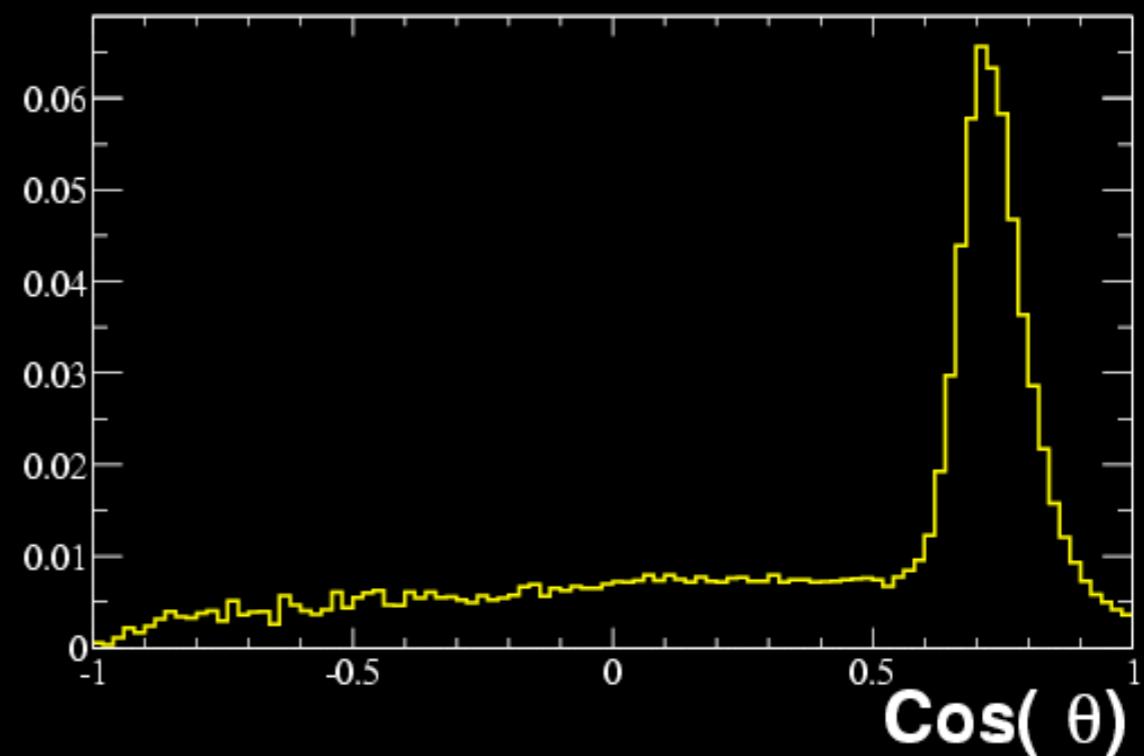
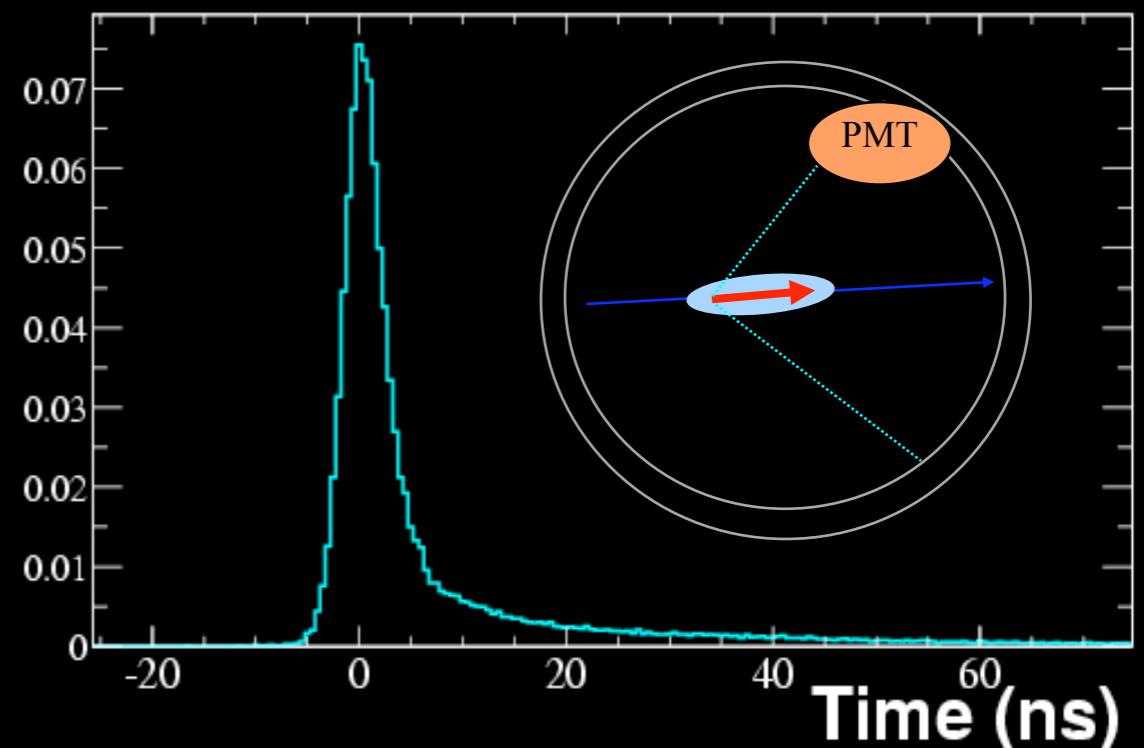
Charged particles produce Cherenkov and scintillation light in oil



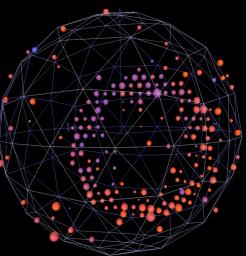
PMTs collect photons, record t,Q

Reconstruct tracks by fitting time and angular distributions

Find position, direction, energy

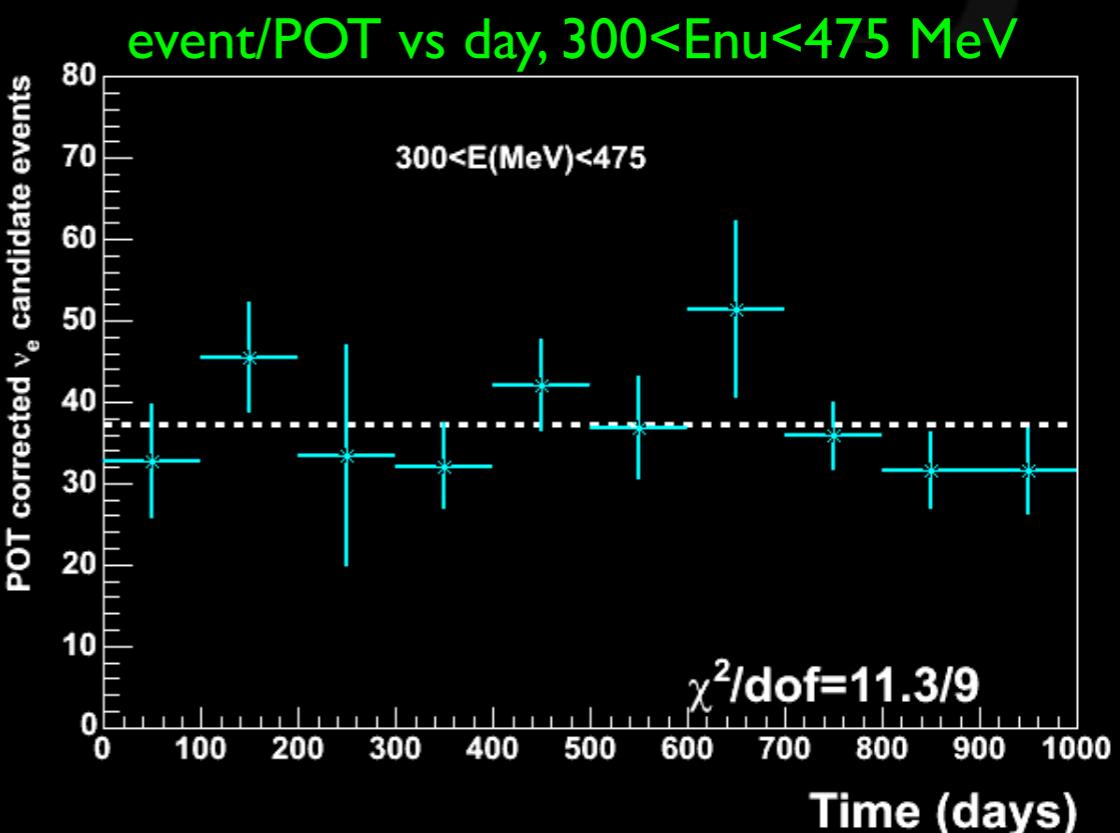
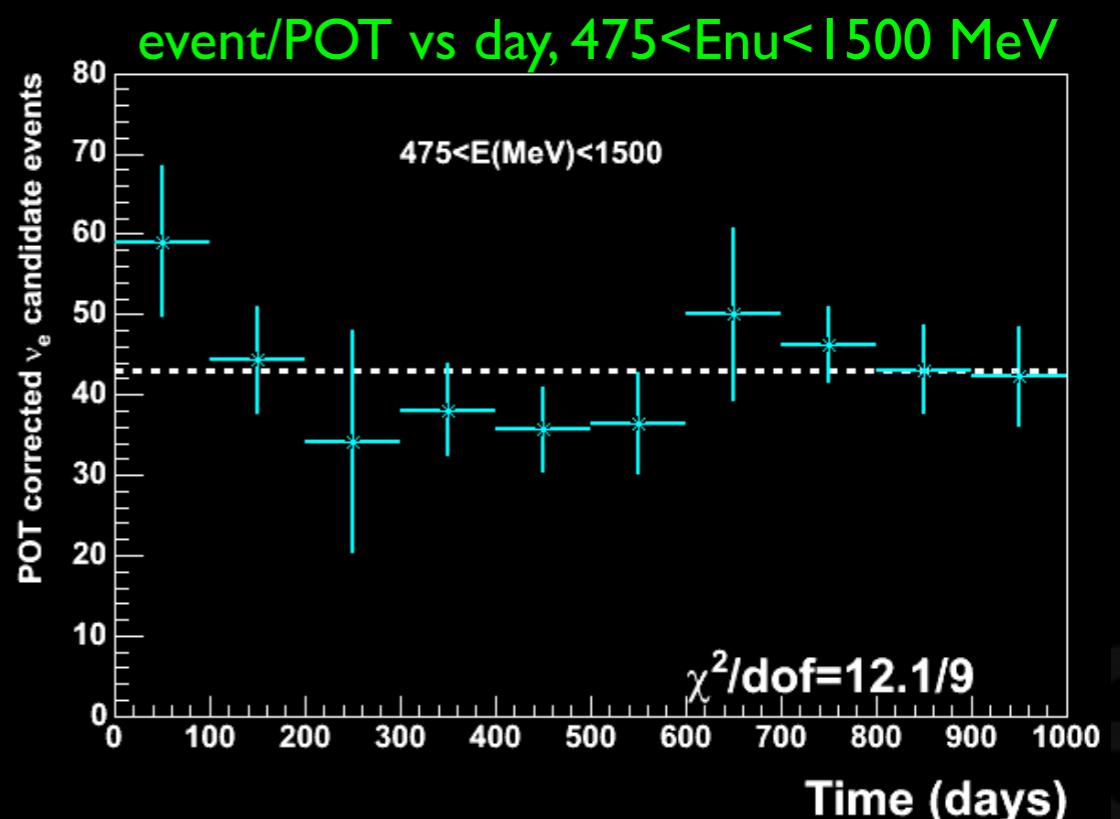
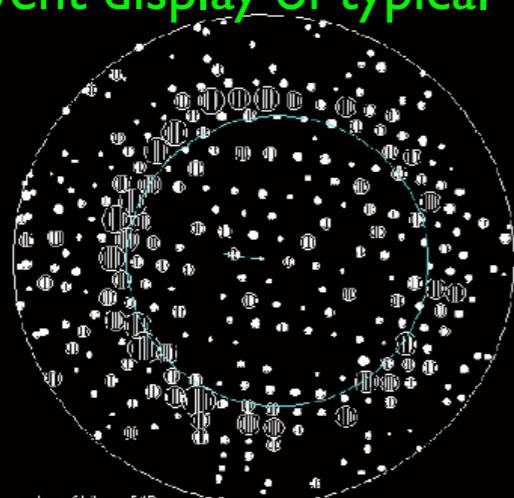


Integrity checks

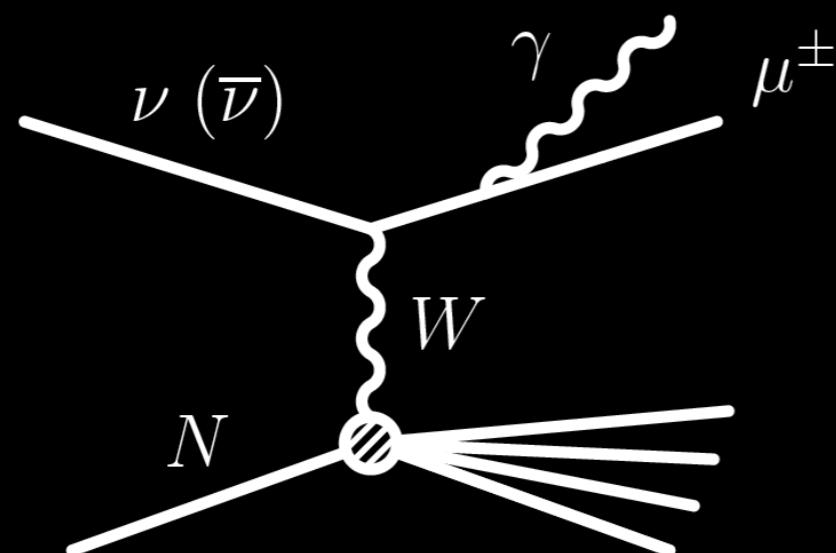
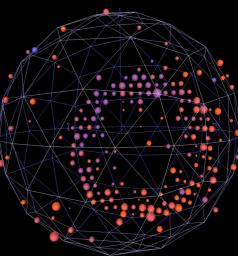


- Detector anomalies: none found
 - Example: time distribution of ν_e events is flat
- Hand scanned all events: nothing pathological found

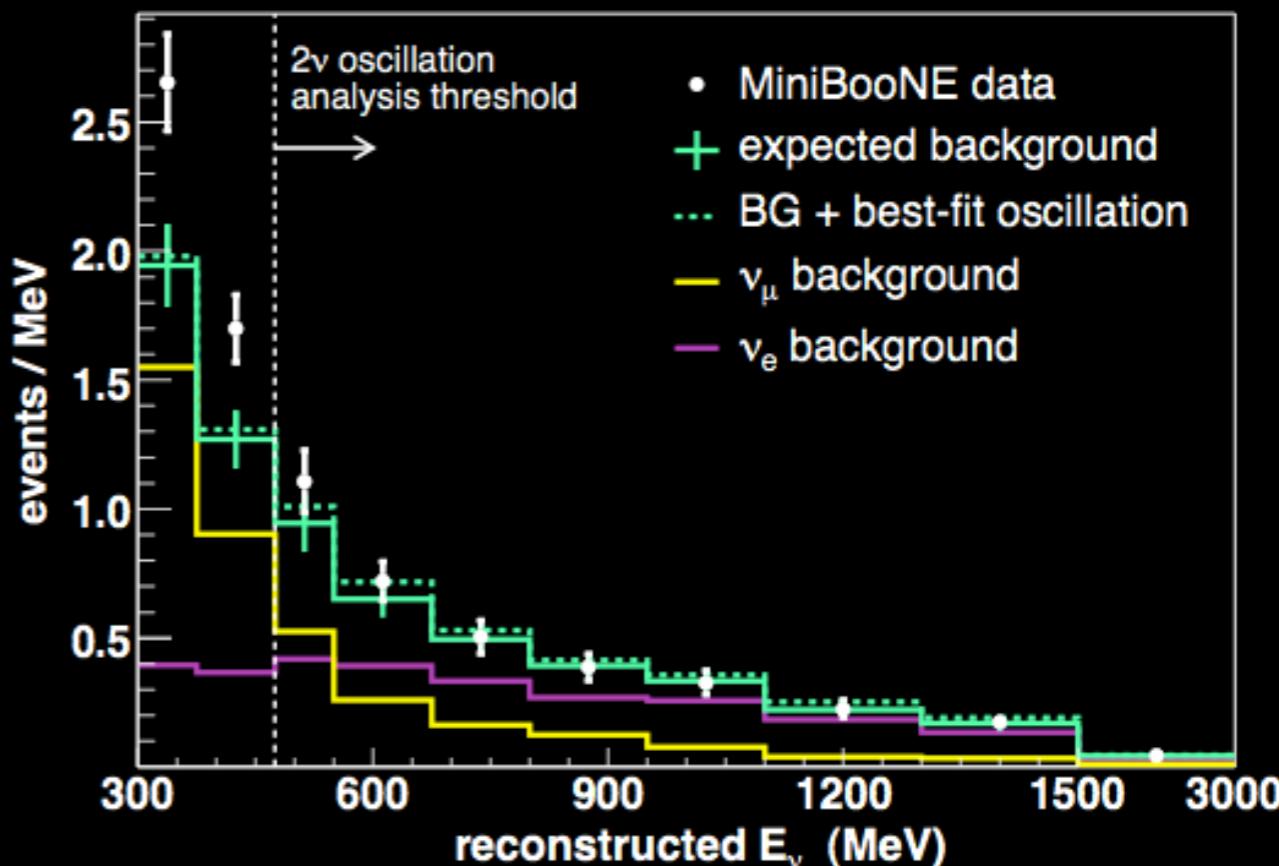
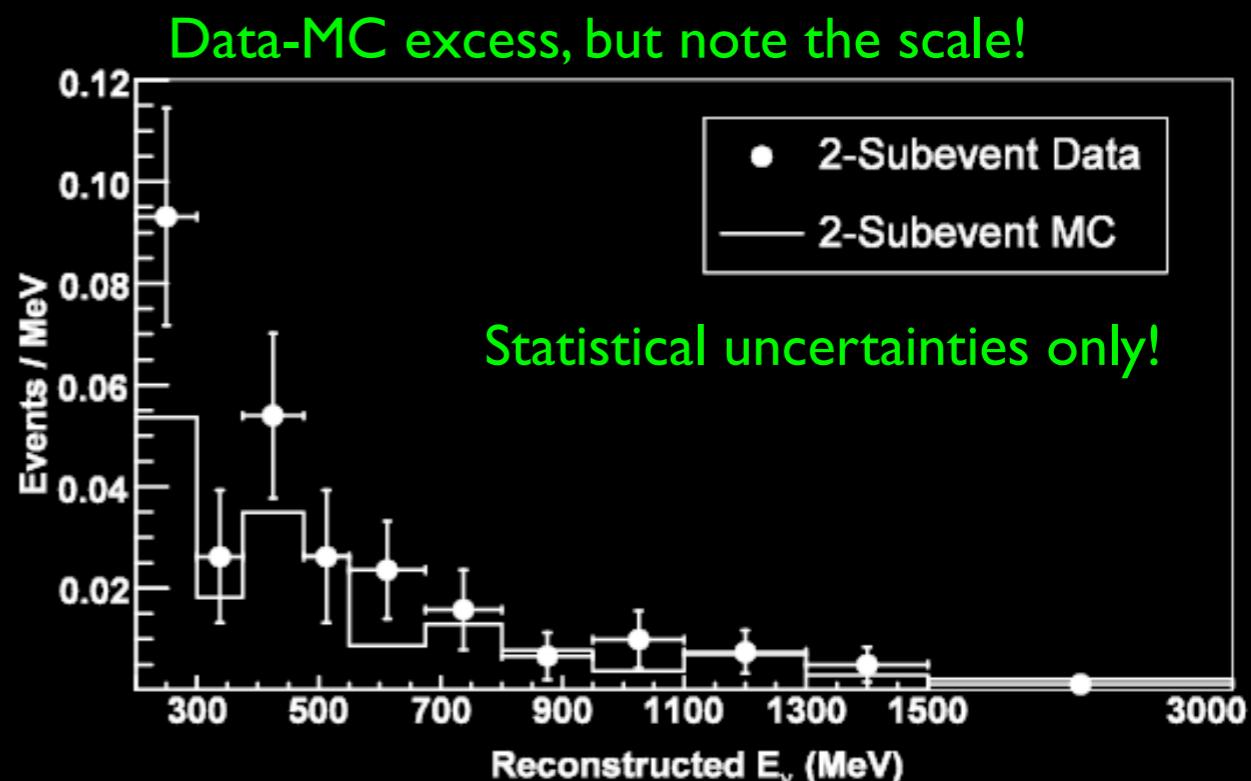
event display of typical ν_e



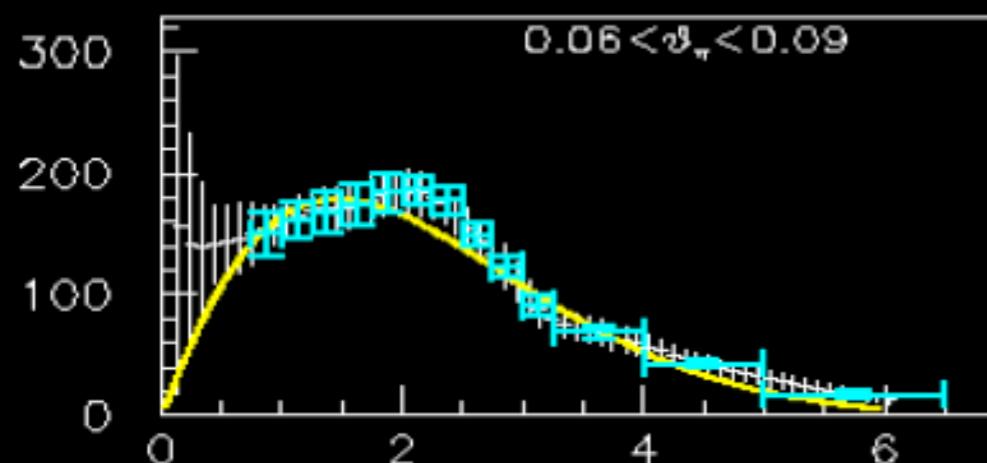
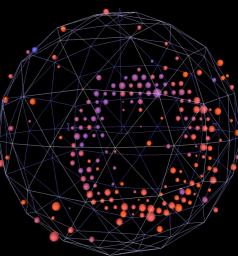
Muon Internal Brem



- Apply recon and PID to clean muon CCQE events
- Directly measure rate of final state muon ν_e backgrounds

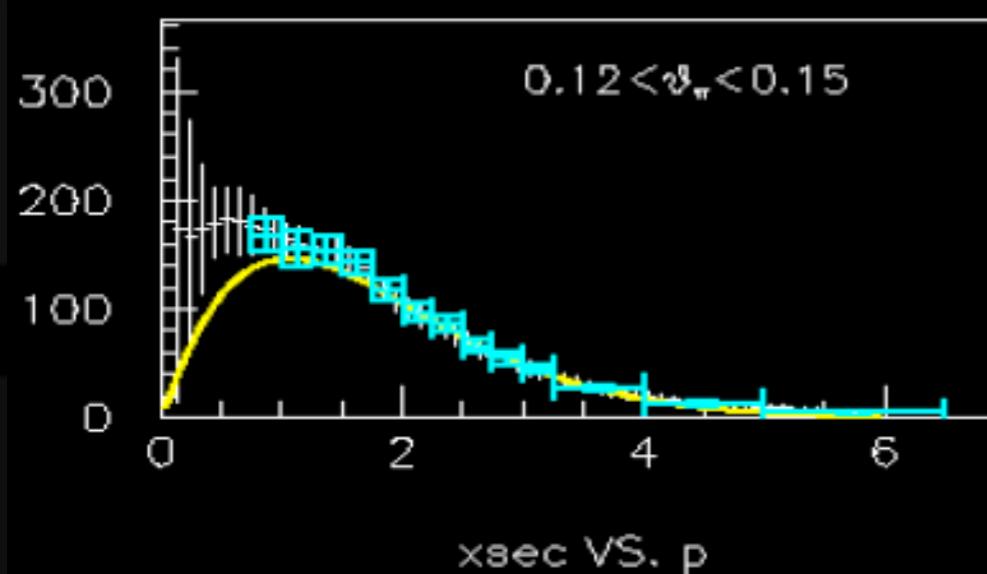


ν Flux Uncertainties

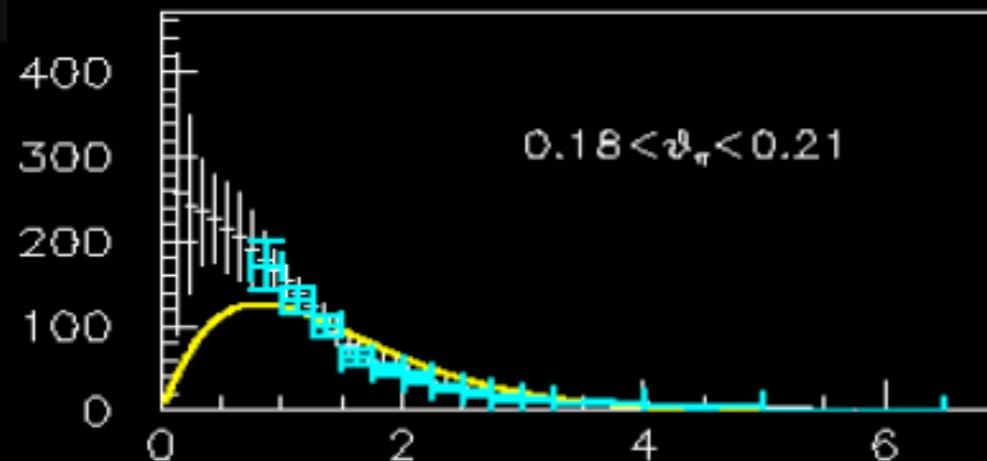


- Now use HARP data and covariance matrix to directly estimate flux uncertainty

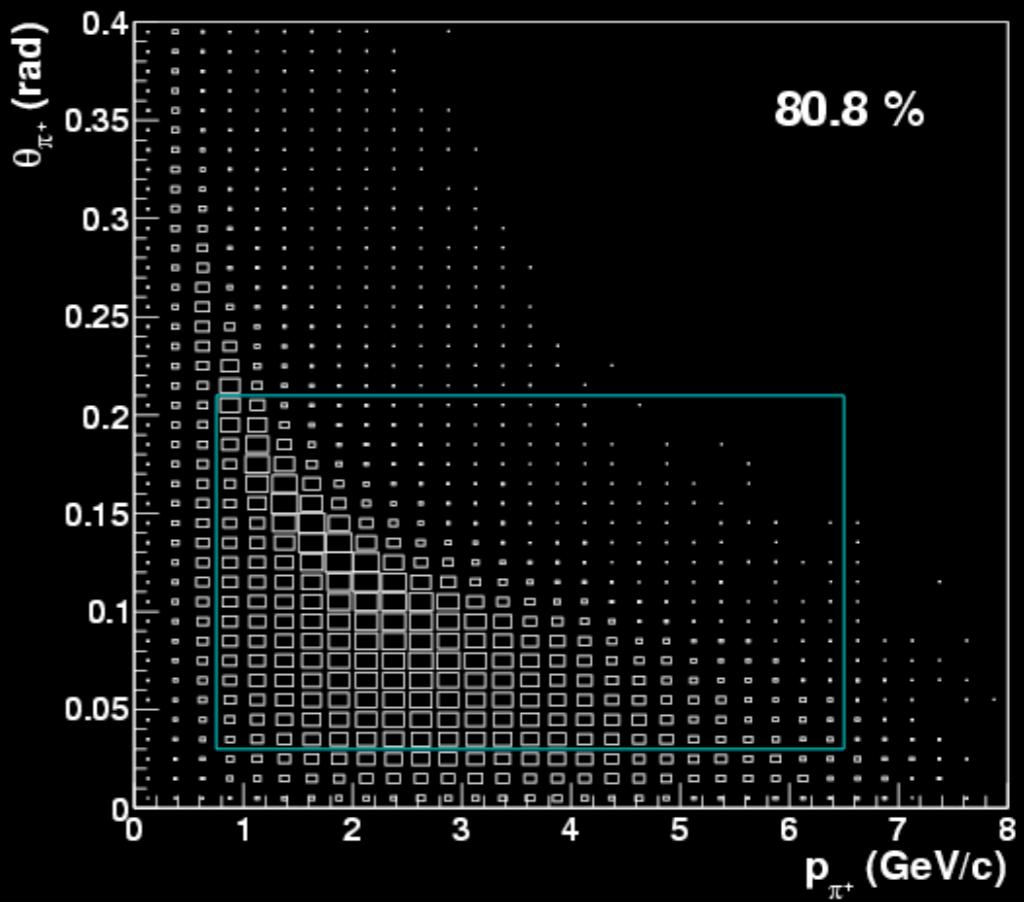
(instead of Sanford-Wang)

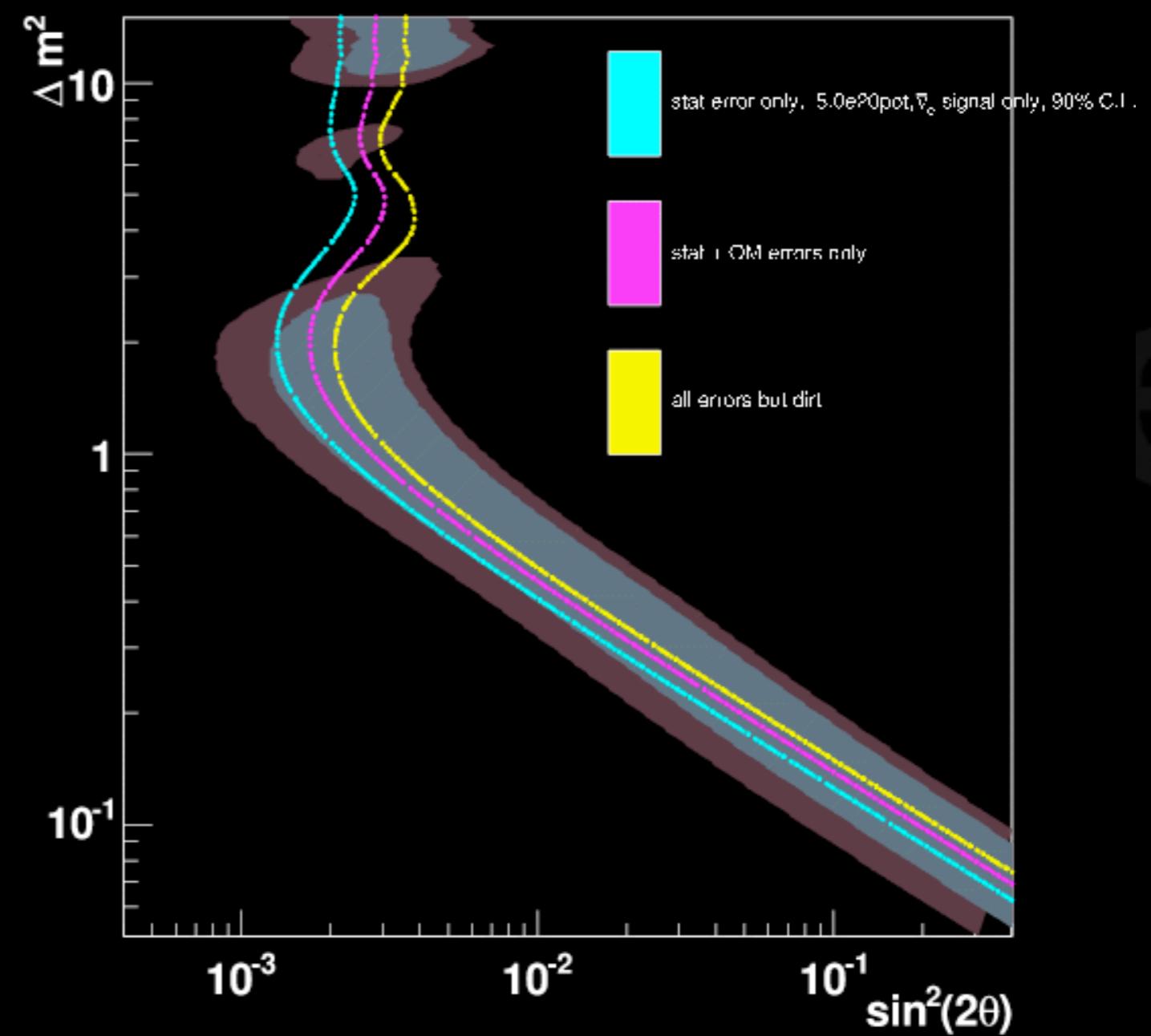
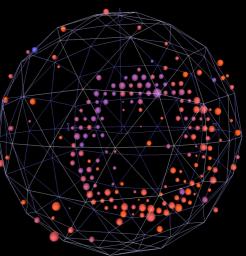


- Excellent coverage of HARP data makes this possible



- 15%-->8%





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